Carbon Gap

CARBON LIMITS

perspectives climate research

CDR Readiness Assessment

# Developing CDR at scale and speed in Norway

MAY 2024

## About Carbon Dioxide Removal (CDR) Readiness Assessments

Many governments have already committed to Net Zero, however no government currently has a robust plan in place to develop and deploy CDR at the capacity required to counteract remaining emissions. The IPCC forecasts the need for hundreds of billions of tonnes of carbon dioxide removal in order to stabilise global temperatures in line with the ambitions of the Paris Agreement. However, most estimates of how much CDR will be required are global in nature and it is unclear what is achievable at a country level. Revealing the potential for CDR deployment at a country level and co-creating country-specific roadmaps with local stakeholders for each country will assist decisionmakers in understanding what opportunities exist and what actions need to be taken to realise them.

## Acknowledgements

This report was prepared by Carbon Limits AS and Perspectives Climate Research gGmbH. The project team thanks Carbon Gap for their trust and participation in, and feedback on, the Background Report on CDR in Norway. The team also thanks The Norwegian Board of Technology (NBT), an independent technology assessment body, for sharing the results of the citizen engagement panel on assessing the impacts and options of CDR for society. We wish to give special thanks to the stakeholders who were interviewed as part of the development of this report. The feedback and discussions with the stakeholders and Carbon Gap helped to pave the way for developing this report. The project team also extends its gratitude to the following workshop participants, for their invaluable contributions to the development of the background report:

| PARTICIPANT NAME | PARTICIPANT COMPANY |
|---|---|
| **Asbjørn Torvanger** | CICERO Center for International Climate Research |
| **Bjørn Huso** | Norwegian Agriculture Agency |
| **Bjørnulf Tveit Benestad** | Down to Earth |
| **Carlos Dinamarca** | SINTEF Industry |
| **Christian Lindemann** | Norwegian Institute for Water Research |
| **Eirik Lilledahl** | Carbon Removal |
| **Eivind Berstad** | The Bellona Foundation |
| **Hans H. Kolshus** | Norwegian Environment Agency |
| **Hanne Rolén** | Aker Carbon Capture |
| **Helene Mørne** | Carbonor AS |
| **Helene Muri** | Norwegian University of Science and Technology |
| **Ingeborg O. Nordraak** | Norwegian Forest Owners' Federation |
| **Jannicke Gerner Bjerkås** | Hafslund Oslo Celsio AS |
| **Jon Bjartnes** | World Wide Fund for Nature |
| **Kaja Killingland** | City of Oslo |
| **Kaja Voss** | Inherit Carbon Solutions |
| **Lars Strøm** | Ocean GeoLoop AS |
| **Linn Viken Bøe** | Skogkurs |
| **Martine Mørk** | Zero Emission Resource Organisation |
| **Rahul Anantharaman** | SINTEF Energy Research |
| **Terje Kronen** | Norwegian Society for the Conservation of Nature |
| **Thomas Hartnik** | Norwegian Institute of Bioeconomy Research |

# Executive Summary

Norway's physical geography, national and international climate policy, and social geography all play a role in the future potential of Carbon Dioxide Removal (CDR) technology deployment in the country. This report evaluates suitability of both technological and nature-based CDR pathways in Norway and details the various geographical, social, and political aspects that could affect their deployment.

## Energy resources

**Norway has a high capacity for future electricity production, but the realization of this potential depends on development of policies and licenses for building additional renewable energy. Several organizations have estimated the future electricity generation in Norway, with most forecasts predicting an electricity surplus if development increases.** Norway has been a net exporter of electricity for 17 of the past 25 years. Most electricity produced in the country (approximately 98% each year) is renewable, mostly from hydropower, and the grid has a high storage capacity. Currently, electricity consumption is expected to increase faster than production until 2030, but production will grow faster in the following decade. The electricity balance is thus expected to be tight for the next 3 decades based on existing licenses, although there is no expected risk of power rationing over the next 5 years. However, untapped potential remains – an estimated 338 GW of offshore wind capacity could possibly be developed. The transmission capacity between the north and south is also expected to improve by up to 60% by 2030. Ultimately, Norway has adequate electricity potential to support CDR scaling, but if the rate of development remains limited, it will constrain the rate at which high-energy demand technologies like DACCS and bio-CCS can be deployed.

**Future thermal energy capacity in Norway will develop based on changes in demand. Geothermal and solar thermal have limited potential in the country, but there is a high untapped potential for energy from biomass and biofuels.** By optimizing the use of existing sources of biomass in Norway, the bioenergy capacity could be almost double if these sources could be economically and sustainably collected and used. Depending on the electricity surplus, part of the electricity could be used to produce heat.

**Biomass is widely used for energy and biofuel production in Norway, but there remains a high potential for additional biomass that could be utilized depending on the accessibility and economic viability of collection procedures.** The primary biomass feedstock in Norway is wood, which is used to manufacture products and produce energy. It's estimated that an additional 4.5 million cubic meters (mcm) of timber can be sustainably harvested beyond current production levels, but current policies around land use, conservation, and other renewable energy sources indicate that the government does not currently plan to increase forestry biomass production. Organic waste is also a significant source of biomass in the country, but national ambitions to reduce food waste by 50% by 2030 will reduce the amount generated in the future. Due to a lack of agricultural land, there are no plans to grow energy crops in Norway. However, substantial additional biomass potential may exist in unutilized or sub-optimally utilized biomass like agricultural residues.

## Other resources for CDR deployment

**There is an abundance of water resources in Norway, but high leakage rates in the dated distribution infrastructure may make it harder to access adequate volumes for CDR deployment.** The country has one of the highest precipitation rates in Europe and 6% of its surface consists of lakes or rivers, which are generally in good condition. Although the per capita water usage is high, only 0.6% of the country's available water resources were withdrawn in 2020. In the long term, climate change is predicted to increase precipitation and heavy rainfall across the country, but changes in precipitation and temperature patterns have already led to some water shortages in the capital city of Oslo. Effects of increased rainfall (i.e. flooding and landslides) may worsen the already deteriorating state of the water distribution infrastructure, which loses up to 30% of municipal water through leaks.

**Norway has a considerable supply of several mineral resources that could be valuable for CDR technologies.** The country has likely the largest reserves of olivine in the world and is responsible for up to half of global production. Dolomite, limestone, and basalt can also be found within the mainland and offshore. Despite a lack of current quantitative estimates for these minerals, the nation has recently stated that it aims to improve mineral resources mapping and project planning. There is also an intention to strengthen the industry around global climate-related value chains, which may include CDR.

## Land and natural conditions

**The Norwegian mainland has a large availability for CDR and CDR related infrastructure deployment.** Much of Norway is covered in natural landscapes, and several land types are subject to protective or restorative policies – for example, Norway prioritizes the preservation of agricultural land. All these factors affect the land area available for CDR and its related infrastructure deployment. When analysing available land in Norway, after accounting for water bodies, wetlands, built environment, proposed protected areas, forests, and arable land, there is still expected to be upwards of 121,000 $km^2$ of land available for infrastructure deployment. Overall, land availability might not pose a significant obstacle for CDR deployment. However, various CDR pathways require different land patterns and climatic conditions tailored to their specific needs. This report delves into the land availability for each CDR pathway, aiming to determine if land constraints will impede any particular CDR approach.

**The extensive Norwegian coastline provides opportunity for various CDR technologies such as kelp farming.** Large-scale kelp farming can both provide a natural carbon sink and reduce ocean acidification. The country is already responsible for 15% of global wild seaweed production, and the estimated production potential off the coast is 20,000 $t/km^2$/year: this corresponds to a capture potential of up to 3,000 $tCO_2/km^2$. However, large scale kelp farming is not yet well understood in terms of environmental effects. Norway's offshore also provides a good environment for direct ocean capture technologies, which perform better in sea water and in colder water temperatures.

**Temperature and humidity changes in Norway are an expected result of climate change, but this is unlikely to have a significant impact on novel CDR potential.** Some novel CDR pathways like Direct Air Carbon Capture and Storage (DACCS) can be sensitive to low temperatures and humidity. Although much of Norway has below-freezing temperatures in the winter, this is not expected to be exacerbated by climate change: annual temperatures are generally expected to increase, more so in the winter than in the summer. Additionally, humidity levels in Norway are currently high and projected decreases are not expected to affect DACCS potential. However, changing climate conditions may affect energy demand and the capacity for nature-based CDR solutions.

## Storage

**Carbon dioxide storage has already been extensively practiced offshore of Norway, and there is plenty of potential for additional capacity.** The Sleipner and Snøhvit oil and gas fields have been storing $CO_2$ since 1996 and 2008, respectively. It is estimated that there is a remaining offshore capacity of between 29 86 $GtCO_2$, and currently planned projects in Norway have a combined storage capacity of 58 Mtpa by 2030. Additionally, the use of timber in durable products can offer another form of carbon storage. Timber demand in the construction industry is expected to grow, offering a nature-based storage solution.

**Norway's carbon management strategy places a focus on Carbon Capture and Storage (CCS) as a crucial means of reducing emissions and moving towards its goal of becoming a low-emission society.** The Norwegian Environmental Agency (NEA) has listed CCS as one of the strategies (along with electrification) with the highest potential for reaching the emissions targets. Climate-related spending in the country has been rapidly increasing in the last decade, but emissions are not falling at the rate that is required to meet emissions reduction targets. It is therefore important to prioritize public spending towards policies like CCS that achieve a short-term but substantial impact.

## Policy and social geography

**Climate policies, incentives, and support mechanisms can both facilitate emissions reductions and encourage investment in research, development, and adoption of mitigation strategies and technologies such as CDR.** Norway largely uses $CO_2$ taxes and emissions trading to drive its climate policies, but also provides financial support and guidance for climate projects under its state-owned Enova support scheme. Furthermore, although there is no regulatory framework specifically established for CDR, there are several regulatory and economic instruments already implemented or under consideration that aim to facilitate technology development and deployment. There is also a large-scale CCS demonstration project under development in the country. Nature-based CDR is supported through national agricultural and forest policies that promote increased carbon sequestration. International policies, such as public mitigation targets, regulatory mandates, subsidies, and carbon pricing instruments can also drive CDRs on a national level. For example, the EU Emissions Trading System is currently considering reforms that could enhance its ability to incentivize CCUS and CDR, and the proposed EU Carbon Removal Certification Framework would help standardize different CDR certification schemes.

**Norway's social geography generally indicates a national commitment to ambitious climate action but a potential lack of skilled workforce.** The nation has pledged alignment with the Paris Agreement and continues to develop climate policies, regulations, and investment. However, Norway continues to produce and export significant amounts of oil and gas, and investments in this industry continue to rise alongside green investments. In order to meet climate ambitions, the emissions from the oil and gas industry will need to be deeply and rapidly reduced. But Norway could go further by advancing the development of CDR and potentially going net negative, to address its responsibility for past emissions and support a fair distribution of decarbonisation efforts globally. The country's wealth puts it in a strong position to implement these strategies. More technical and engineering skills will be required in Norway for CDR deployment, but the high labour market participation and skilled workforce provides a good base for development in this arena.

**The national focus on climate efforts is reflected in the public landscape, but climate action and solutions remain socially complex.** Almost 70% of the Norwegian public acknowledges responsibility towards emissions reductions. However, oil and gas exploration has been, and continues to be, a significant part of the Norwegian economy and is the topic of many political discussions related to climate change and national profits. In the long term, a transition away from the oil and gas industry could provide the opportunity for Norway to develop a larger CDR industry. However, the social landscape around this transition will be multifaceted: it will require balancing national needs for oil and gas production, opposing sentiments on CDR and emissions reduction strategies, landscape and biodiversity considerations, and cultural heritage interests – especially those of the indigenous Sami people.

## Deployment pathway

Based on the high-level theoretical potential estimated, **bio-CCS and DACCS rank higher on the list since they are technologically more advanced that other CDR pathways, and the reductions are more traceable compared to nature-based solutions.** Kelp farming is another CDR pathway that is highly relevant for Norway due to the country's prior experience in kelp production and the availability of ocean area for kelp farming. Reforestation also has a good potential in Norway, provided there is ample monitoring of the forest health. **This ranking is relatively in line with the findings from the workshop, where stakeholders placed priority on bio-CCS, DACCS, reforestation, improved forest management, biochar, and blue carbon (or kelp farming) as the most politically relevant CDR methods for Norway.** Stakeholders also raised the issue of permanence when it comes to reforestation and improved forest management.

**High-level theoretical potential estimates in Norway show a good potential for both nature-based and technology-based CDR pathways.** The following table summarizes the high-level theoretical potential estimated for CDR pathways relevant for Norway. The report further details the assumptions used and the scenarios for estimating the theoretical potential. Finally, the future work or further assessment required to estimate a more realistic potential are presented in the report.

| CDR pathway assessed | Theoretical potential estimated for 2030 ($MtCO_2$ pa) | Theoretical potential estimated for 2050 ($MtCO_2$ pa) |
|---|---|---|
| **DACCS (Solid state DAC (S-DAC))** | 2 – 14 | 9 – 88 |
| **DACCS (Liquid state DAC (L-DAC))** | 2 – 11 | 8 – 71 |
| **Bio-CCS (BECCS)** | 1.8 – 2.4 | 9 – 10 |
| **Biochar (Pyrolysis)** | 0.8 – 1.1 | 3.2 – 4.6 |
| **Coastal enhanced weathering (CEW)** | 1 – 7 (Estimate for a batch process – unclear whether annual or less/more frequent. Assuming 2-10% of shoreline availability) | |
| **Terrestrial enhanced weathering (TEW)** | 3.5 – 4.4 (Estimate for a batch process – unclear whether annual or less/more frequent. Assuming all the arable land is used and density of spreading around 2 kt of basalt per $km^2$) | |
| **Kelp farming** | - | 6 – 9 (Could be achieved by 2050 assuming seaweed production of 20 $kt/km^2/year$) |
| **Ocean liming** | 4 – 5 (Estimate for a batch process – unclear whether annual or less/more frequent) | |
| **Total potential** | Cannot be summed up as some pathways will lead to competition between resources | Cannot be summed up as some pathways will lead to competition between resources |

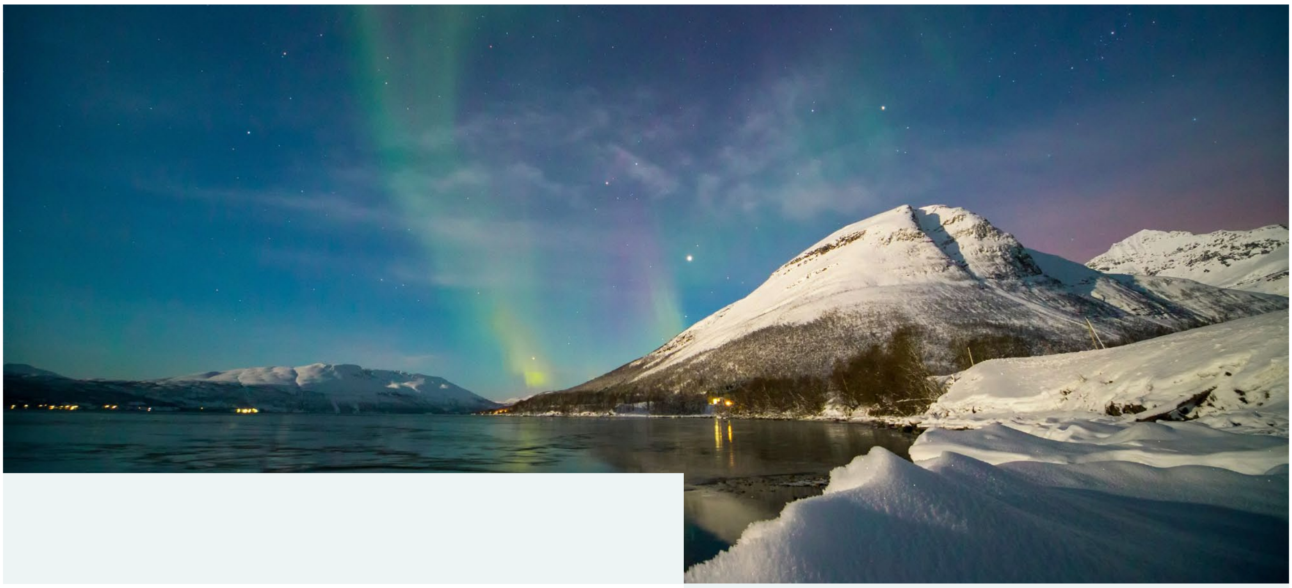
**Table 0. Summary of theoretical potential estimated for CDR pathways assessed in Norway. More details on the assumptions and scenarios are presented in the main report.**

**Based on the emission reduction targets set by Norway, by 2050 Norway will still have 2.5 – 5 Mt $CO_2$eq to curb to reach net-zero.** This is comparatively a small quantity considering the high CDR potential in Norway, which could be met through a combination of the low-hanging bio-CCS potential and Norway's reforestation plan alone.

The significant remaining CDR potential in Norway could help the country go beyond net-zero and remove more $CO_2$ from the atmosphere, provided the infrastructure development is also improving at a rate required for CDR deployment.

To put emissions in context, Norway's oil and gas exports can lead to 400 – 500 $MtCO_2$ of combustion emissions[1] in importing countries. While these emissions may not be accounted for within the country's borders, Norway has a good opportunity to go beyond net-zero and support the global achievement of Paris Agreement targets. While CDR cannot compensate for ongoing fossil emissions, by leading the development of CDR scale-up, and potentially going net-negative, Norway can demonstrate global leadership in climate change mitigation. **Furthermore, owing to its $CO_2$ storage capacity potential, Norway could also be a net $CO_2$ importer to help store $CO_2$ removed/captured in other countries.** This underscores the critical importance of policy alignment and infrastructure enhancement to harness Norway's substantial capacity for CDR and effectively contribute to global climate change mitigation efforts.

1 Only $CO_2$ emissions associated with burning oil and natural gas, Value chain emissions (transport, processing / refining, distribution) are not considered in this estimation.



© Lightscape - Unsplash

# Table of Contents

© Taneli Lahtinen - Unsplash

## List of Abbreviations

| | |
|---|---|
| **AC** | Alternating current |
| **aFRR** | Automatic Frequency Restoration Reserve |
| **AR6** | Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change |
| **BAU** | Business as usual |
| **bcm** | Billion cubic meters |
| **BECCS** | Bioenergy with carbon capture and storage |
| **Bio-CCS** | Bio-energy carbon capture and sequestration |
| **$CaCO_3$** | Calcium carbonate |
| **CaO** | Calcium oxide |
| **CAPEX** | Capital expenses |
| **CCS** | Carbon capture and sequestration |
| **CCUS** | Carbon capture, utilization and sequestration |
| **CDD** | Cooling Degree Days |
| **CDM** | Clean Development Mechanism |
| **CDR** | Carbon dioxide removal |
| **CEW** | Coastal enhanced weathering |
| **CL** | Carbon Limits |
| **$CO_2$** | Carbon dioxide |
| **$CO_2e$** | Carbon dioxide equivalents |
| **CRCF** | Carbon Removal Certification Framework |
| **DAC** | Direct air capture |
| **DACCS** | Direct air carbon capture and sequestration |
| **DC** | Direct current |
| **ECHR** | European Court of Human Rights |
| **EEA** | European Economic Area |
| **ELA** | European Labour Authority |
| **ENGO** | Environmental non-governmental organisations |
| **ESR** | Effort Sharing Regulation |
| **ETO** | Energy Transition Outlook |
| **ETS** | Emission Trading System |
| **EU** | European Union |
| **EUR** | Euro (€) |
| **EV** | Electric vehicle |
| **FID** | Final investment decision |
| **GDP** | Gross domestic product |
| **GHG** | Greenhouse gases |
| **GSHP** | Ground source heat pumps |
| **Gt** | Giga-tonne |
| **GW** | Gigawatts |
| **HDD** | Heating Degree Days |
| **IEA** | International Energy Agency |
| **IMF** | International Monetary Fund |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IRENA** | International Renewable Energy Agency |
| **km** | Kilometre |
| **$km^2$** | Square kilometres |
| **Kt** | Kilotonne |
| **kV** | Kilo-Volt |
| **LCA** | Life cycle assessment |
| **L-DAC** | Liquid solvent direct air capture |

| | |
|---|---|
| **LFS** | EU Labour Force Survey |
| **LNG** | Liquefied natural gas |
| **LPG** | Liquefied petroleum gas |
| **LT-LEDS** | Long Term – Low Emission Development Strategy |
| **LULUCF** | Land use, land use change, and forestry |
| **$m^3$** | Cubic meters |
| **mcm** | Million cubic meters |
| **mm** | Milli-meter |
| **MRV** | Monitoring, reporting, and verification |
| **Mt** | Million tonnes |
| **Mtpa** | Million tonnes per annum |
| **MW** | Megawatts |
| **NATO** | North Atlantic Treaty Organization |
| **NCCS** | Norwegian CCS Research Centre |
| **NDC** | Nationally determined contribution |
| **NGU** | Norge Geologiske Undersøkelse |
| **NOK** | Norwegian krone |
| **NPD** | The Norwegian Petroleum Directorate |
| **NREL** | National Renewable Energy Laboratory |
| **NSL** | North Sea Link |
| **NTC** | Net Transfer Capacity |
| **NVE** | Norway's Directorate of Water Resources and Energy |
| **O&G** | Oil and gas |
| **OAE** | Ocean alkalinity enhancement |
| **OECD** | Organisation for Economic Co-operation and Development |
| **OPEX** | Operational expenses |
| **pH** | Potential of Hydrogen |
| **PJ** | Petajoules |
| **PV** | Photovoltaics |
| **QGIS** | Quantum Geographic Information System |
| **R&D** | Research and development |
| **RCP** | Representative Concentration Pathway |
| **RDD&D** | Research, design, development, and demonstration |
| **RMP** | Regionalt miljøtilskudd i jordbruket (Norway Regional Agro-environmental Programme) |
| **S-DAC** | Solid sorbent direct air capture |
| **SSB** | Statistisk Sentralbyrå |
| **STEM** | Science, technology, engineering, and mathematics |
| **t** | Tonnes (metric) |
| **TCM** | Technology Centre Mongstad |
| **TEW** | Terrestrial enhanced weathering |
| **TRL** | Technology readiness level |
| **TSO** | Transmission system operator |
| **TWh** | Terawatt-hour |
| **UCO** | Used cooking oil |
| **UNFCCC** | United Nations Framework Convention on Climate Change |
| **USD** | United States Dollar ($) |
| **VCM** | Voluntary carbon market |
| **WtE** | Waste-to-energy |

## List of Figures

## List of Tables



© Secret Travel Guide - Unsplash

# 1. Introduction

While climate change progresses[2,3], unfolding more and more tangible and catastrophic impacts, many governments and private actors have committed to Net Zero by mid-century, in line with the objectives of the Paris Agreement.[4] Rapid and far-reaching emissions cuts are key to achieving the bulk of the progress towards this goal, but actors must also plan for sufficient capacity to remove carbon dioxide from the atmosphere to neutralize their residual emissions.

Carbon Dioxide Removal (CDR) refers to "anthropogenic activities removing $CO_2$ from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products".[5] The climate impact of carbon removal is called 'negative emissions' and is now broadly considered as the third pillar of climate action: reduce, adapt, remove.

In its 6th assessment report,[6] the IPCC signals the need to remove hundreds of billions of tonnes of $CO_2$ from the atmosphere by the end of the century if we are to stabilize climate change at levels compatible with the Paris agreement. More recent reports keep confirming the magnitude of the CDR challenge.[7,8]

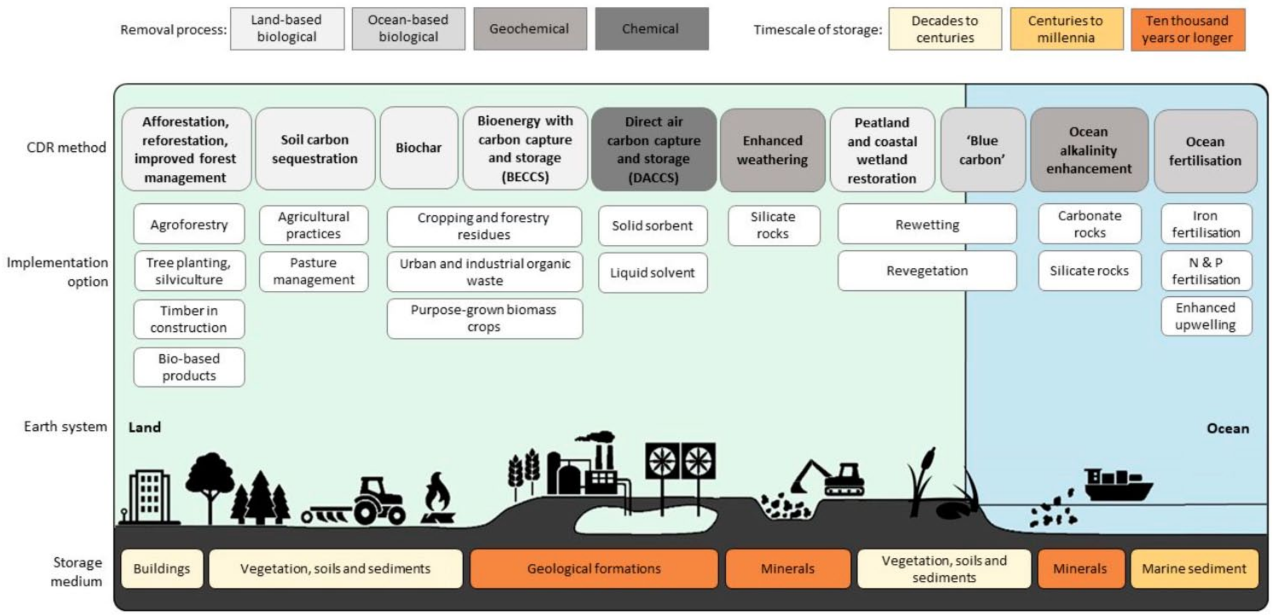



**Figure 1: CDR pathways presented in the IPCC AR6 report.[9]**

2 World Meteorological Organization. State of the Global Climate 2023. 2024.
3 Schmidt G. Climate models can't explain 2023's huge heat anomaly — we could be in uncharted territory. Nature. 2024 Mar 21;627(8004):467–467.
4 UNFCCC. Paris Agreement on Climate Change UNFCCC. 2015.
5 Intergovernmental Panel On Climate Change (Ipcc), editor. Technical Summary. In: Climate Change 2022 - Mitigation of Climate Change [Internet]. 1st ed. Cambridge University Press; 2023 Available from: www.cambridge.org/core/product/identifier/9781009157926%23pre3/type/book_part
6 IPCC. Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2022;
7 European Environment Agency., European Scientific Advisory Board on Climate Change. Scientific advice for the determination of an EU-wide 2040 climate target and a greenhouse gas budget for 2030–2050. Available from: https://data.europa.eu/doi/10.2800/609405
8 Climate Overshoot Commission. Reducing the Risks of Climate Overshoot. 2023.
9 IPCC. Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. 2022;

Yet very few governments have a robust plan to develop and deploy CDR at the required scale. An array of reasons explains this situation, among them the lack of clarity on how much CDR should countries aim for (targets), how much they can realistically deploy (their potential), and on how to achieve a successful and rapid development of this new sector (the means). Indeed, the estimations of the required volumes of CDR are currently only available at global level, and there is a lack of granular data on the capacities of individual countries to deploy CDR. Such estimations are largely based on modelling,[10] accounting for only a subset of the existing CDR methods[11] hence with limited capacity to explore the trade-offs and competition for resources in a systemic way.[12] Moreover, existing studies focus on the technical challenge, largely overlooking the level of awareness and endorsement of CDR by national stakeholders and the general public,[13] which are key variables to define how much CDR can be deployed and highly variable from country to country.

To develop a realistic plan and accelerate the deployment of carbon dioxide removal technologies, a detailed assessment of existing resources and their level of availability at country level is necessary, as well as engaging with key stakeholders and the public in each country.

To fill this information gap and help countries accelerate the deployment of CDR, Carbon Gap is conducting the Country CDR readiness assessment project. Inspired by the Renewables Readiness Assessments released by the International Renewable Energy Agency (IRENA), this project aims to estimate the potential for CDR deployment at national level, and to co-create country-specific roadmaps. These roadmaps lay out a detailed plan to successfully deploy CDR on a significant scale and are drafted with the active participation of national stakeholders in each country, to help decision-makers identify the best approaches to support CDR deployment. This report presents a bottom-up assessment of CDR theoretical potential in Norway and presents a case study of optimal portfolio of CDR methods for deployment.

The report begins with an overview of existing CDR methods, and details which methods are considered in this study. The resource requirements to operate CDR (energy, water, land, storage, etc.) are characterized for the selected methods.

The report then assesses the availability of the various resources required, considering the constrained volumes and the essential (priority) non-negotiable uses. Beyond the current situation of the considered resources, possible trends are also analysed, to assess whether additional volumes can be generated to mitigate the competition of CDR with existing uses.

To complete this first part of the report, the current regulatory environment is analysed to identify the enabling and limiting factors for the development of CDR processes. Using published data, the report provides an overview of the structure of the Norwegian economy, its political landscape, and attitudes regarding climate change, as well as documented characteristics of Norwegian society.

By combining the maximum volumes of resources theoretically available with the requirements by method, and within the limits of the regulatory framework, the theoretical maximum potential for deploying negative emissions is estimated.

This report has been used as an information base to develop a roadmap of actions required to accelerate the deployment of CDR in Norway, which was designed jointly by the project team and a sample of key stakeholders in Norway. The roadmap is published in a separate document. The project brought together a network of key stakeholders in Norway to develop this roadmap and it is our hope that this group will be instrumental in promoting its recommendations to policymakers - ensuring that the roadmap is not only actionable, but also put into action.

In addition to the background report and the roadmap, the Norwegian Board of Technology (NBT) conducted a citizen engagement panel on assessing the impacts and options of CDR for Norwegian society. The results of this panel engagement are summarized in the Annex 5 of this report. This work has been commissioned by Carbon Gap, a non-profit organisation which is advocating for accelerating the development and deployment of carbon removal in Europe.

10 Rickels W, Proelß A, Geden O, Burhenne J, Fridahl M. Integrating Carbon Dioxide Removal Into European Emissions Trading. Front Clim. 2021 Jun 24;3:690023.
11 Rosa L, Sanchez DL, Mazzotti M. Assessment of carbon dioxide removal potential via BECCS in a carbon-neutral Europe. Energy Environ Sci. 2021;14(5):3086–97.
12 Lefebvre D, Fawzy S, Aquije CA, Osman AI, Draper KT, Trabold TA. Biomass residue to carbon dioxide removal: quantifying the global impact of biochar. Biochar. 2023 Oct 11;5(1):65.
13 NEGEM project. Member State specific pathway for NETP deployment. 2023.

## 2. Country's physical geography

A crucial part of preparing for CDR deployment in a country is to understand its physical geography and the country's suitability for different CDR pathways. To perform this study, the authors assessed aspects including land and resource availability, storage potential, and the energy system to provide background information on Norway's suitability for CDR deployment. While data sources on existing conditions were accessible publicly, little information was available on future or committed resources. For sectors facing a lack of data, interviews with relevant industry stakeholders were used to supplement the information presented in this section.

### 2.1. Norway's energy landscape

The availability of energy, especially clean and renewable energy, plays an important role in shaping the potential of CDR technologies in a given region. Implementation of certain CDR technologies, for example DACCS or Bio-CCS, requires significant inputs of electricity and/or heat. The following sections examine Norway's energy landscape, including the status today, the potential and distribution of key renewable sources, such as hydropower, wind, and solar energy in the following years.

#### Total energy production and consumption

Norway's energy production and consumption profile, and in particular the availability of low-carbon energy sources, will strongly shape its ability to deploy energy-intensive CDR methods. **Today, over 90% of the primary energy produced in Norway is from oil and natural gas. The vast majority of this production (98% of oil and gas production) is exported to other countries, as shown in Table 1.**

When it comes to energy consumption, the industrial sector is the largest consumer of energy (namely as electricity and heat), accounting for almost 32% of final energy consumption in Norway in 2022. Norway's energy system is thus highly carbon intensive.

| Category | Value in 2022 (TWh) |
|---|---|
| Primary energy production | 2,510 |
| *Of which, oil and gas production* | *2,345* |
| Imports | 135 |
| Exports | 2,335 |
| *Of which, oil and gas exports* | *2,307* |
| **Total energy supply*** | **296** |
| **Energy industry own use** | **66** |
| **Distribution losses** | **8** |
| **Final consumption** | **241** |
| Non-energy consumption | 23 |
| Final energy consumption (Industry) | 76 |
| Final energy consumption (Transport) | 56 |
| Final energy consumption (Household) | 45 |
| Final energy consumption (Other) | 42 |

* Removing international bunkers and accounting for the stock changes for supply. Note: Statistical difference between supply and consumption of 20 TWh

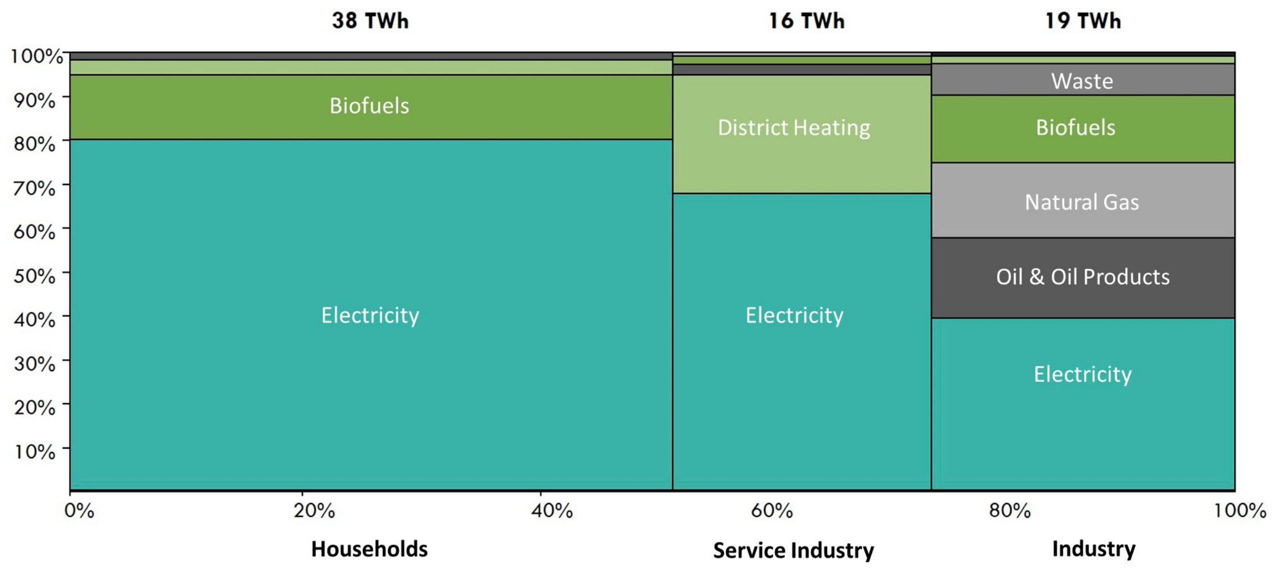
**Table 1: Supply and use of energy in Norway, Energy Balance in TWh (2022)[14]**

14 Statistisk Sentralbyrå. (2023). Production and consumption of energy, energy balance and energy account. https://www.ssb.no/en/energi-og-industri/energi/statistikk/produksjon-og-forbruk-av-energi-energibalanse-og-energiregnskap

### Thermal energy production and consumption

Thermal energy is not universally required for all CDR technologies, however several CDR pathways, especially technology-based pathways, such as DACCS and BECCS, involve chemical processes that require thermal energy. Availability of thermal energy from renewable fuels is hence an important aspect to consider for CDR deployment. **Thermal power production in Norway is relatively limited in scale, with production matching the consumption.**

Figure 2 summarizes the energy utilized for heating and cooling in Norway in 2018. In Norway, heat comes from a range of sources, with households mainly electrified, while industry still draws heavily on fossil fuels (50%). In the case of heat used in industries, studies carried out by SINTEF and Norsk Industri show that around 20 TWh of low temperature heat is wasted every year.[15] This waste heat can be used within the industries producing the heat, or nearby industries such as land-based hatchery and breeding, horticulture and general heating/district heating of homes, commercial buildings, sports facilities, etc.[16]




* Source as presented in the reference: Energy balance 2018 (SSB 2019), Asplan Viak, Oslo Economics. Added energy in TWh. The categorization follows SSB's statistics internal link. Waste: denotes waste used in industry for heating. Spill heating is incl. heat from waste incineration.

**Figure 2: Demand for heating and cooling in 2018, in TWh/year[17]**

### Forecast of Norway's thermal energy landscape

Norway's total thermal energy demand is expected to be relatively flat, while observing some redistribution of the fuel sources being used. It is expected that the demand for electrified heat will increase, leading to a reduction in demand for oil, natural gas, and biomass for thermal energy production. Thermal energy capacities will be expanded based on expected demand in the country.

In terms of overall capacity for thermal energy production using renewable energy sources, the potential for solar thermal and geothermal are considered low.[18] Geothermal capacity, primarily delivered through ground source heat pumps (GSHP), is primarily inhibited by cost.

For biomass for thermal energy generation, Norway has significant room for growth, with estimates that bioenergy could grow by 20 TWh/year based on feedstock availability estimates (more information about this is provided in Section 2.5). However, competition with demand from the smelting industry could constrain this availability.[19]

15 Europower Energy. (2021). 20 *TWh overskuddsvarme fra norsk industri.* www.fjernvarme.no/20-twh-overskuddsvarmefra-norsk-industri
16 Norsk Industri. (2016). *Veikart for prosessindustrien – økt verdiskaping med nullutslipp i 2050.* www.norskindustri.no/siteassets/dokumenter/rapporter-og-brosjyrer/veikart-for-prosessindustrien_web.pdf
17 Statistisk Sentralbyrå. (2023). Production and consumption of energy, energy balance and energy account. www.ssb.no/en/energi-og-industri/energi/statistikk/produksjon-og-forbruk-av-energi-energibalanse-og-energiregnskap
18 IRENA. (2023). Energy Profile: Norway. www.irena.org/-/media/Files/IRENA/Agency/Statistics/statistical_profiles/europe/norway_europe_re_sp.pdf
19 Carbon Limits analysis using information from SINTEF paper: Everson, N. et al. (2023). *What is the potential of BioCCS to deliver negative emissions in Norway? From biomass mapping to a window of negative emissions potential.* https://psecommunity.org/LAPSE:2023.36828

### Electricity production and consumption

The sources of electricity available in Norway will shape the deployability of CDR, with certain methods relying on a supply of low-carbon electricity to ensure $CO_2$ removal can be achieved over the full lifecycle.

**Norway's electricity production is predominantly renewable. The proportion of renewable electricity may fluctuate with energy prices and weather conditions, but it stands at approximately 98% in a typical year.**[20] While the power sector in Europe will continue undergoing a significant transformation, replacing fossil power production with intermittent renewable power, the transformation of the power sector in Norway will not be as dramatic.[21]

In 2022, Norway produced approximately 146 TWh of electricity, of which 88% was produced by hydropower plants. The Norwegian hydropower system has a very high storage capacity, with the total reservoir capacity capable of delivering more than 70% of Norway's annual electricity demand.[22]

As with total energy, the industrial sector is the largest consumer of electricity, accounting for roughly 46% of the net electricity consumed in Norway in 2022. Table 2 summarizes the electricity balance in Norway as of 2022.

| Category | 2022 (TWh) | Share (%) |
|---|---|---|
| **Total electricity production** | **145.9** | **100%** |
| Hydro power production | 128.7 | 88% |
| Thermal power production | 2.4 | 2% |
| Wind power production | 14.8 | 10% |
| **Imports** | **13.3** | |
| **Exports** | **25.8** | |
| **Gross consumption** | **133.4** | |
| Pump storage & losses | 8.3 | |
| Net consumption | 125.2 | 100% |
| *Final consumption (Industry)* | *57.9* | *46%* |
| *Final consumption (Services)* | *27.1* | *22%* |
| *Final consumption (Household & agriculture)* | *40.0* | *32%* |

**Table 2: Electricity production and consumption in Norway in 2022 (TWh)**[23]

**Norway has been a net electricity exporter in 17 of the past 25 years. Norway's power trading capacity with other countries is currently about 8,900 MW. In the last 10 years, the power balance has improved, and Norway has had an average net export of about 10 TWh/year.**[24] Table 3 provides an overview of existing Norwegian cross-border power trading capacities. Norway's position as a net exporter of electricity could have implications on CDR deployment. While Norway might be bound by electricity supply contracts, there is potential to use the electricity surplus for CDR deployment. More information on the electricity production forecast in Norway is presented in the next sub-section.

20 IRENA. (2023). *Renewable Capacity Statistics 2023.* www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023
21 IRENA. (2023). *Renewable Capacity Statistics 2023.* www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023
22 Energifakta Norge. (2023). *Electricity Production.* https://energifaktanorge.no/en/norsk-energiforsyning/kraftproduksjon/
23 Statistisk Sentralbyrå. (2023). *Electricity.* www.ssb.no/en/energi-og-industri/energi/statistikk/elektrisitet
24 Energifakta Norge. (2023). *The Power Market.* https://energifaktanorge.no/en/norsk-energiforsyning/kraftmarkedet/

| Border | Name | Max NTC Export capacity: | AC / DC | Operational? |
|---|---|---|---|---|
| **Norway - Sweden** | Several lines on the various borders | 3,695 MW | AC | In operation |
| **Norway - Denmark** | Skagerrak 1 - 4 | 1,700 MW (But 100 MW is reserved for aFRR[26] most of the time) | DC | In operation |
| **Norway - Netherlands** | NorNed | 700 MW | DC | In operation |
| **Norway – Germany** | NordLink | 1,400 MW | DC | In operation |
| **Norway – Great Britain** | NSL (North Sea Link) | 1,400 MW | DC | In operation |

**Table 3: Norwegian cross-border power capacities[25]**

### Forecast of Norway's electricity landscape

When it comes to forecasting the energy landscape in Norway, there are a wide range of possible outcomes that will depend on technical potential and political will. Several consulting companies have forecasted the potential electricity generation in Norway – these were summarized in a 2021 report by NVE.[27] Forecasts made in the report are based on licences for power project development issued as of 2021 in Norway. As per the report, some licences might not be converted to actual projects – hence several scenarios were considered.

As per the NVE report, power consumption is expected to increase until 2030, at a rate faster than electricity production in Norway. This conclusion is shared by reports by consultancy Thema (2022) and grid operator Statnett (2021). Between 2030 and 2040 however, power production is expected to grow more rapidly, strengthening the power balance in Norway. All in all, electricity balance in Norway is expected to be tight for the next 3 decades. Figure 3 shows the range of existing projections for electricity consumption in 2030, 2040 and 2050 and Table 4 summarizes the electricity production, consumption and surplus forecasts in Norway between 2030 and 2050.

| Projections | 2030 | 2040 | 2050 |
|---|---|---|---|
| **Projections** | 2030 | 2040 | 2050 |
| **Electricity production** | 166 – 203 | 185 – 253 | 206 – 269 |
| **Electricity consumption** | 159 – 188 | 174 – 213 | 190 – 232 |
| **Surplus** | 7 – 15 | 11 – 40 | 16 – 37 |

**Table 4: Projected electricity production, consumption and surplus in Norway between 2030 and 2050[28]**

25 Norwegian Water Resources and Energy Directorate (NVE). (2023). *Norway and the European power market.* www.nve.no/norwegian-energy-regulatory-authority/wholesale-market/norway-and-the-european-power-market/
26 The automatic Frequency Restoration Reserve (aFRR), also known as secondary reserve, is a reserve in the power grid that helps to keep the grid frequency stable.
27 Norwegian Water Resources and Energy Directorate (NVE). (2023). *Varme.* www.nve.no/energi/energisystem/termisk-energi/varme/
28 NVE (2021), Statnett (2021), Thema og Multiconsult (2022), DNV GL (2021), Prosess21 (2020)

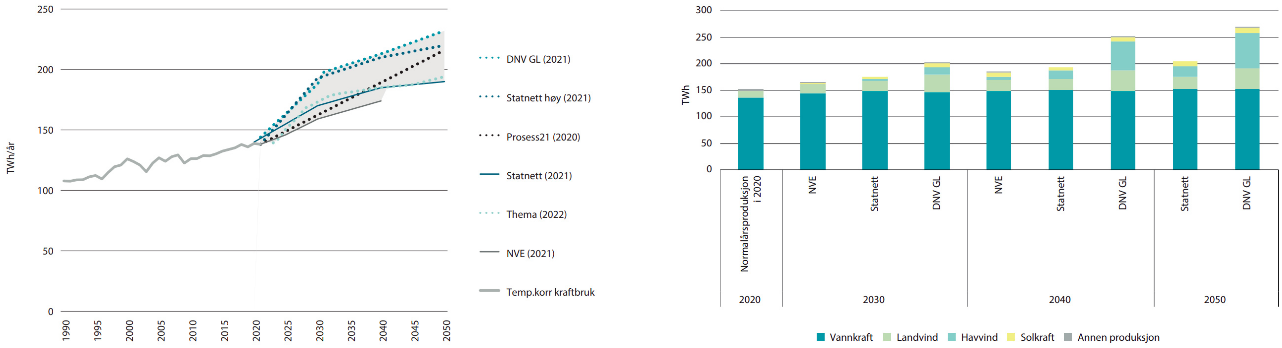



**Figure 3: (Left) Projections of electricity consumption in 2030, 2040 and 2050. (Right) Projections of electricity production in 2030, 2040 and 2050.[29]**

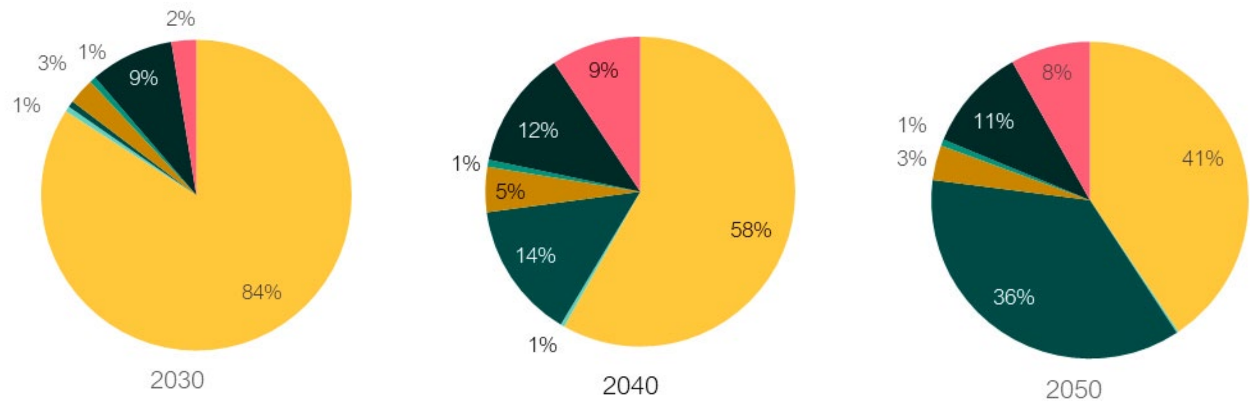



**Figure 4: Projected electricity production by source in 2030, 2040 and 2050[30]**

While the references above present forecasts of electricity generation and consumption, there are several reports that predict a much higher renewable energy potential in Norway. As per the IRENA estimate of renewable resource potential, Norway has a very high potential for onshore wind energy, and low potential for solar energy (Figure 5).

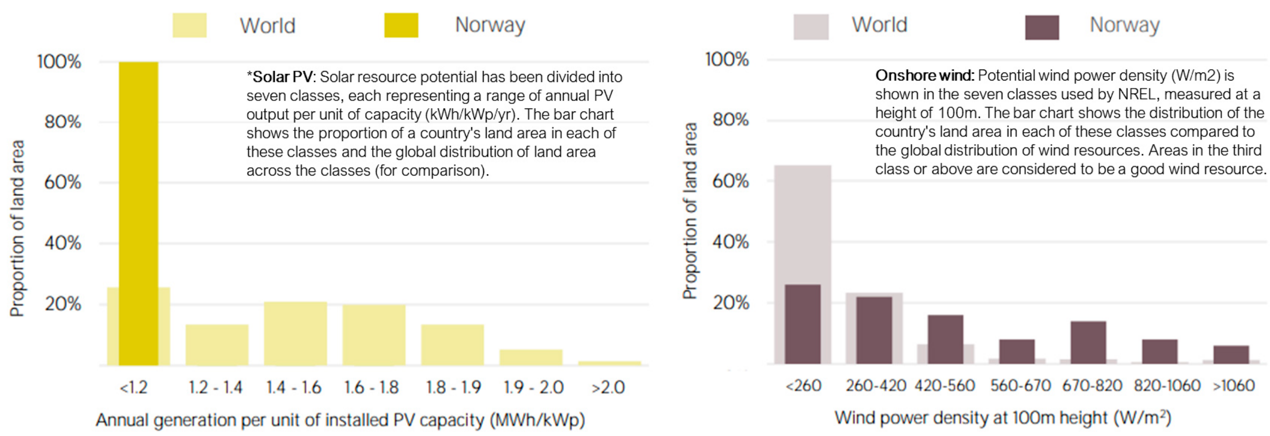


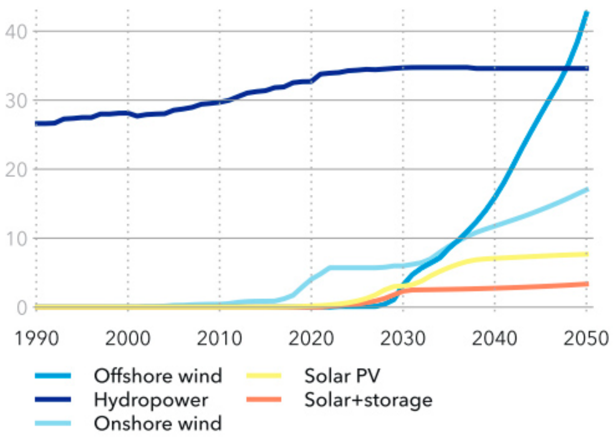

**Figure 5: Distribution of solar (Left) and onshore wind (Right) energy potential in Norway[31]**

**29** IRNVE (2021), Statnett (2021), Thema og Multiconsult (2022), DNV GL (2021), Prosess21 (2020)
**30** DNV. (2022). *Energy Transition: Norway 2022.* **www.dnv.com/Publications/energy-transition-norway-2022-235535**
**31** IRENA. (2023). *Energy Profile: Norway.* **www.irena.org/-/media/Files/IRENA/Agency/Statistics/statistical_profiles/europe/norway_europe_re_sp.pdf**

Wind capacity in Norway has potential to grow, 300 GW of offshore wind possible in the areas suggested by the Norwegian Water Resources and Energy Directorate (NVE).[32] But expansion will be shaped by social acceptability of renewable energy installations and the rate of development of supportive policy. Most capacity is expected to be developed offshore, constituting an estimated 80% of wind-based generation in 2050.[33]

**Norway grid and off-grid installed renewable capacity**

Units: GW




**Norway capacity additions becoming operational by power station type**

Units: GW/yr

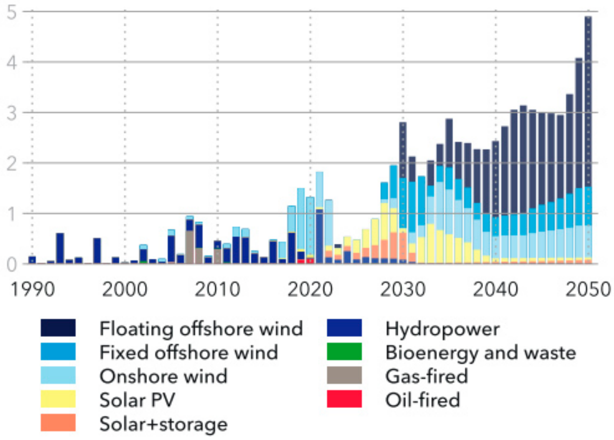



**Figure 6: Projection of renewable energy capacities installed as per Norsk Industri's assessment[34]**

Table 5 presents the electricity generation projection in Norway as per Norsk Industri's analysis and combines it with the information on electricity consumption presented in Table 4 above.

| Projections | 2030 | 2040 | 2050 |
|---|---|---|---|
| **Projections** | 2030 | 2040 | 2050 |
| **Electricity production** | 192 | 277 | 402 |
| **Electricity consumption** | 159 – 188 | 174 – 213 | 190 – 232 |
| **Surplus** | 4 – 33 | 64 – 103 | 170 – 212 |

**Table 5: Projected electricity production, consumption and surplus in Norway between 2030 and 2050[35]**

Statnett (state-owned transmission system operator (TSO)) has considered the consequences of increasing electrification for the power grid, and assumed that the Norwegian power system adequacy, although strained at times, poses no risk of power rationing within the next five years. Grid capacity is another key issue – planned activities in Sweden and Norway are expected to improve overall north-south transmission capacity by 50-60% by 2030.[36]

32 Hjorth, R. et al. (2023). *Norway's 300 GW offshore wind opportunity.* https://media-publications.bcg.com/norways-300-gw-offshore-wind-opportunity.pdf
33 Multiconsult (2023). www.norwegianoffshorewind.no/news/new-report-possible-to-build-338-gw-of-offshore-wind-in-norway/
34 DNV. (2022). *Energy Transition: Norway 2022.* www.dnv.com/Publications/energy-transition-norway-2022-235535
35 Carbon Limits analysis using information from Norsk Industri, Energy Transition in Norway (2022), NVE (2021), Statnett (2021), Thema og Multiconsult (2022), DNV GL (2021), Prosess21 (2020)
36 Norwegian Ministry of Climate and Environment. (2021). *Norway's Climate Action Plan for 2021-2030.* www.regjeringen.no/contentassets/a78ecf5ad2344fa5ae4a394412ef8975/en-gb/pdfs/stm202020210013000engpdfs.pdf

Overall, for the deployment of some CDR technologies in Norway, constraints on electricity and thermal energy will have the most impact. Considering the high wind energy potential in Norway, the emphasis will be on policy support for the development of renewable energy in the country. This includes development of electricity generation systems and transmission gridlines to support the growing electricity generation and consumption in the area. Support from Norwegian public plays a significant role in renewable energy deployment in Norway. Hence public consultation should be considered as an important step while developing targets for renewable energy development in Norway. Further analysis on Sweden, Denmark and Finland's electricity production and cross-border electricity exchange would also be beneficial in understanding the overall electricity surplus in the Scandinavian region.

## 2.2. Norway's water resources

Several CDR pathways require the use of fresh water for $CO_2$ removals from the atmosphere. Apart from the energy requirements, it is crucial to look into the water availability and demand in the country to understand what could be available for CDR deployment in the country. As a result of climate change, precipitation levels and quality of rainwater could be affected, making it more important to assess the freshwater availabilities in the country.[37]

Annual precipitation and surface and groundwater are the major sources of freshwater in Norway. On average, the country receives about 544 billion cubic metres (bcm) of precipitation every year, one of the highest in all of Europe.[38] Autumn months generally get the most precipitation, but some inland areas get more during the late summer months.[39] Norway also has approximately 393 bcm of annual renewable freshwater resources from surface water and groundwater.38 There are 455,000 lakes in Norway, but the largest rivers and catchment areas can be found in the south-eastern part of the country.[40] A map depicting estimated annual rainfall and freshwater resources in Norway is shown in Figure 7.

Groundwater reservoirs in Norway are generally small, with some exceptions particularly in eastern Norway.[41,42] Groundwater levels vary depending on the landscape (i.e. lowlands, mountainous areas, coast), climate, and season. In the lowlands, levels peak twice a year: once in the spring (after the snow melts) and once in the autumn (due to rainfall). Coastal areas which typically receive rain year-round will see maximum groundwater levels in the late winter months.

Over 84% of Norway's population is connected to the municipal water system: in 2022, nearly 0.6 bcm of water was delivered to the country's inhabitants using 52,000 km of pipelines.[43] Around 10% of the population obtains water from private wells and small water plants. Despite the high-water usage in the country (Norwegian residents used nearly twice as much water as Danish residents, on average, in 2018), Norway has plenty of remaining water resources – in 2020, the country withdrew only 0.6% of its available freshwater resources.[44,45]

Norway's water distribution infrastructure, while extensive, is outdated. Approximately 30% of municipal water volume is lost through leaks and is therefore at risk of contamination from adjacent drainage pipelines, and repair rates are slow – at current rates it would take almost 150 years to adequately renovate the system.[46]

37 US Environmental Protection Agency (EPA). (2023). *Climate Change Impacts on Freshwater Resources.* **http://tiny.cc/uin7yz**
38 Food and Agriculture Organization of the United Nations (FAO). (2020). *AQUASTAT database.* **https://tableau.apps.fao.org/views/ReviewDashboard-v1/country_dashboard**
39 Energifakta Norge. (2023). *The Electricity Grid.* **https://energifaktanorge.no/en/norsk-energiforsyning/kraftnett/**
40 European Environment Agency. (2017). *3. Surface water quality monitoring – summary: Norway.* **www.eea.europa.eu/publications/92-9167-001-4/page015.html**
41 Norges Geologiske Undersøkelse (Norway Geological Survey). (n.d.) *Groundwater resources.* https://www.ngu.no/geologiske-ressurser/grunnvannsressurser
42 Norges vassdrags- og energidirektorat (Norwegian Water Resources and Energy Directorate). (2023). *Grunnvann.* **www.nve.no/vann-og-vassdrag/vannets-kretsloep/vannet-under-bakken-markvann-og-grunnvann/grunnvann/**
43 Statistisk sentralbyrå (Statistics Norway). (2023). *Municipal water supply.* **www.ssb.no/en/natur-og-miljo/vann-og-avlop/statistikk/kommunal-vannforsyning**
44 Borgan, E. (2019). *Vi sløser med vannet i Norge. Det får konsekvenser for klima og miljø.* **https://forskning.no/biologi-hus-og-hjem-kjemi/vi-sloser-med-vannet-i-norge-det-far-konsekvenser-for-klima-og-miljo/1567885**
45 FN-Sambandet (United Nations Association of Norway). (2020). *Vannforbruk.* **www.fn.no/Statistikk/vannforbruk**
46 Steinberg, M. and Hyllestad, S. for the Norwegian Institute of Public Health. (2017). *Drinking water in Norway.* **www.fhi.no/en/he/hin/infectious-diseases/drinking-water-in-Norway/?term=**

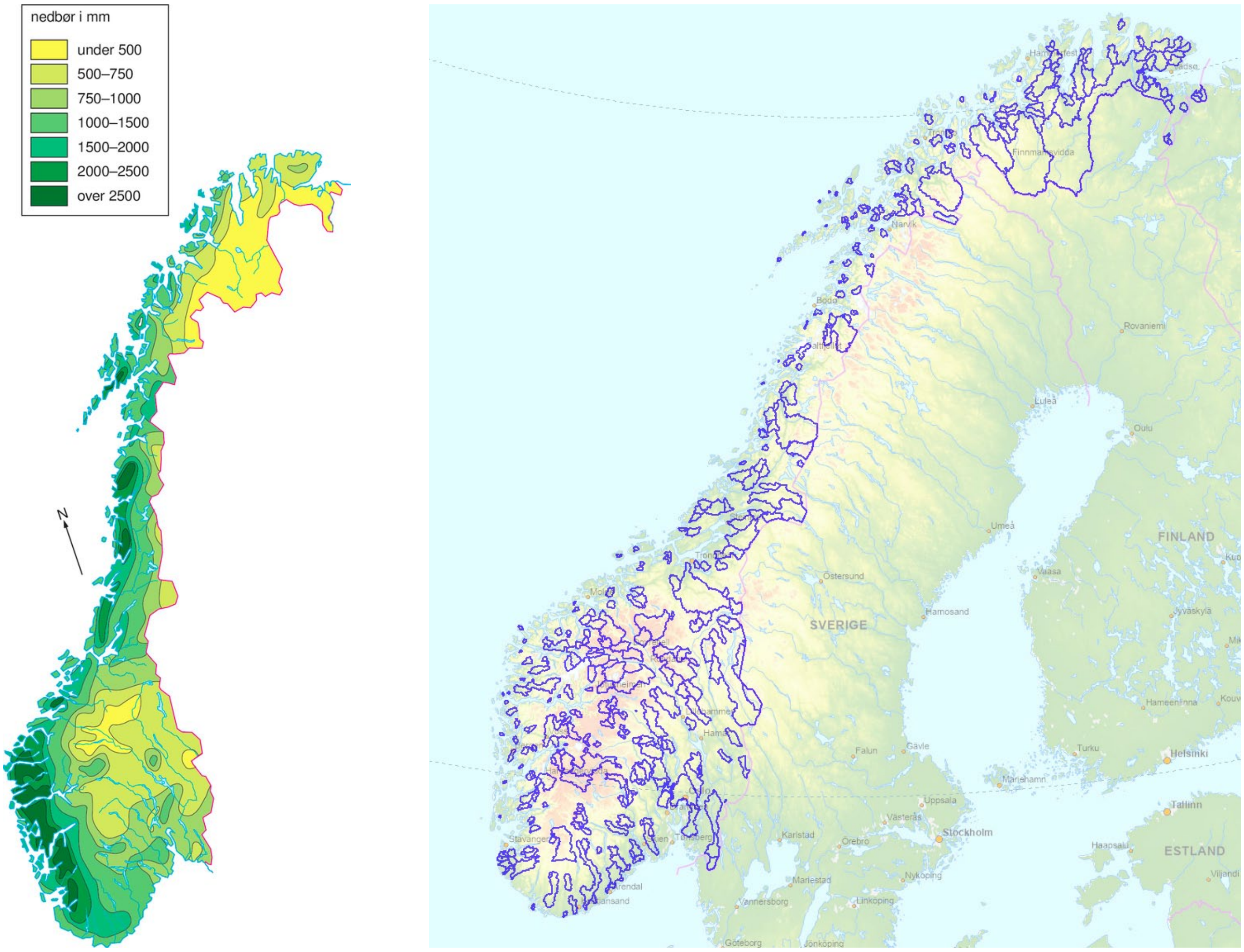



**Figure 7: (Left) Map of annual rainfall precipitation in Norway. (Right) Freshwater sources in Norway[48]**

In the long-term, both annual precipitation volumes and the number of days with heavy rainfall are projected to increase for all seasons across the country.[49]

Under a "business as usual" scenario, median projections predict an 18% increase in precipitation and 89% increase in number of days with heavy rainfall by 2100.In turn, the effects of increased heavy rainfall (i.e., landslides and flooding) are likely to increase the number of pipeline repairs needed. Flooding as a result of heavy rain is expected to increase in frequency and intensity in the future. A map illustrating the percent change in 200-year flood intensity under a "business as usual" scenario (RCP8.5)[50] across the country is shown in Figure 8.

According to the assessment of climate change adaptation for Norway, runoff changes could positively affect the country's hydropower generation overall, although investments in reservoir capacity and power infrastructure may be required to fully realise the anticipated benefits.[51]

49 Hanssen-Bauer, I. et al. (2017). *Climate in Norway 2100.* **www.miljodirektoratet.no/globalassets/publikasjoner/M741/M741.pdf**

50 RCP8.5 refers to a Representative Concentration Pathway (RCP) used in climate modeling. RCP8.5 represents a scenario of high greenhouse gas emissions and is often considered a "business as usual" pathway, where emissions continue to rise throughout the 21st century without significant efforts to mitigate climate change.

51 International Energy Agency. (2022). *Norway Climate Resilience Policy Indicator.* **www.iea.org/articles/norway-climate-resilience-policy-indicator**

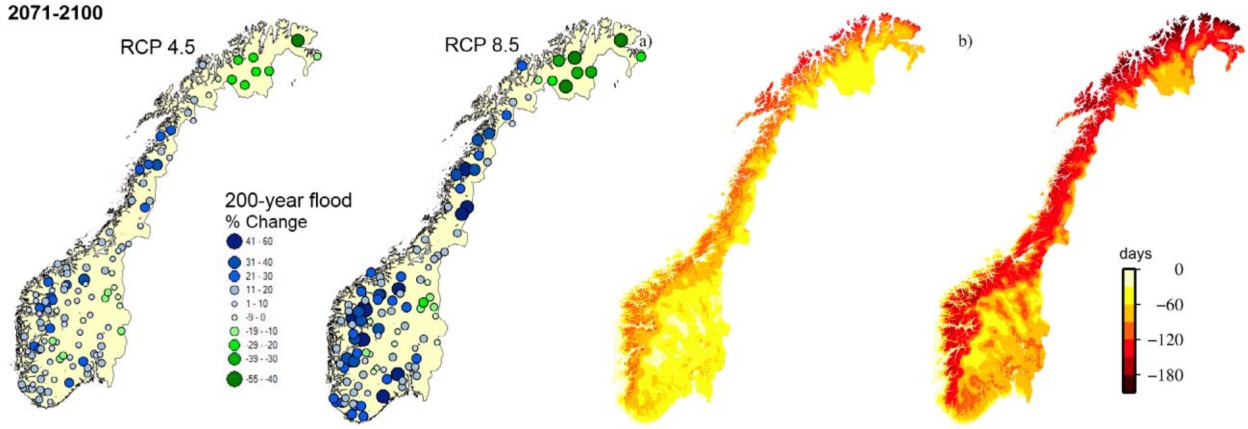



**Figure 8: (Left) Percentage change in the 200-year flood for medium (RCP4.5) and high (RCP8.5) emissions. (Right) Changes in the annual number of days with snow cover from 1971-2000 to 2071-2100 for a) RCP4.5, median projection and b) RCP8.5, median projection.[52]**

In terms of water availability for CDR deployment, the access to freshwater sources could be limited due to the dated distribution system rather than being restricted by the quantity of freshwater available in the country. A more in-depth analysis at the municipality level would be required to gauge the projected availability in selected locations.

## 2.3. Land coverage in Norway

Land is an important factor to take into consideration during the deployment of CDR technologies. Firstly, a large land area would be required for the physical development of most CDR pathways. Based on the pathway deployed, this area must be at a significant distance from protected land resources and residential areas. Further criteria such as fertility of land or natural weather conditions in the area add additional constraints to the selection of suitable land areas for CDR deployment. This section describes the overarching land area types and protected areas in Norway, making high level conclusions on the geographical suitability of Norwegian areas for CDR deployment.

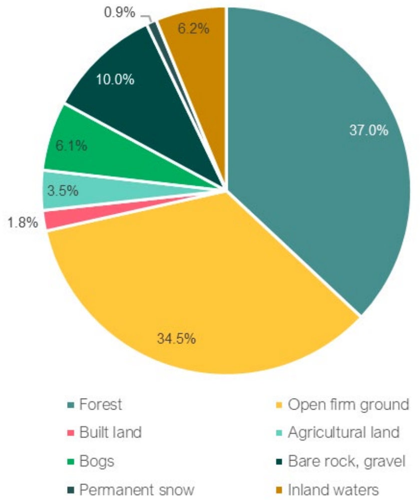
Norway spans over 385,207 km$^2$ and has a diverse landscape with much of the country covered by mountains and forests, with Arctic tundra in the north. River valleys and coastal fjords divide the mountainous landscapes, and upwards of 200,000 mostly uninhabited islands lie off the country's lengthy coastline.

Approximately 37% of Norway's land surface is forested, representing the largest share of land cover in the country. 70% of this area is considered productive, meaning that at least 1 cubic meter of wood can be grown per hectare per year. However, the overall ecological condition of Norway's forests is considered "relatively poor" with an indicator value of 0.41, where 0.6 is considered "good" and 1.0 is considered "pristine".[53] This condition is projected to worsen in the future, mostly due to development and human activities. Approximately 76% of the productive forest is privately owned by individuals and 7.5% by co-owners and companies – together this represents the largest share of privately owned forest in Europe.[54]

Other natural areas (inland waters, bogs, bare rock/gravel, and permanent snow and glaciers) represent another 23.2% of land cover, whereas approximately 3.5% of land is developed for agriculture. The conservation of agricultural land in Norway is currently a priority, although some is still endangered by development and urbanization.[55] Only 2.2% of Norway's land is considered arable by the Food and Agriculture Organization.[56]

52 Hanssen-Bauer, I. et al. (2017). *Climate in Norway 2100.* www.miljodirektoratet.no/globalassets/publikasjoner/M741/M741.pdf
53 Miljødirektoratet, the Norwegian Environment Agency
54 Gundersen, Vegard, et al. (2022). *Forest owners' perspectives on forest protection in Norway.* DOI: 10.1080/02827581.2022.2075448
55 Klima- og miljødepartementet (Ministry of Climate and Environment). (2021). *Norway's Climate Action Plan for 2021-2030.* www.regjeringen.no/contentassets/a78ecf5ad2344fa5ae4a394412ef8975/en-gb/pdfs/stm202020210013000engpdfs.pdf
56 Food and Agriculture Organization. (2020). *Arable Land (% of land area) – Norway.* https://data.worldbank.org/indicator/AG.LND.ARBL.ZS?end=2020&locations=NO&start=1961&view=chart

Norway has an extensive coastline; the most updated estimate of total coastal length is 104,600 km.[57] The mainland coastline constitutes less than a third of this length; most of the coastline is found along Norway's many fjords and islands.[58] It is estimated that the over 5,000 km$^2$ of coastal zone is already influenced by human activity such as infrastructure (buildings, railways, roads) and agriculture. However, over 11,000 km$^2$ are still considered "potentially accessible" and may present opportunities for coastal enhanced weathering.[59]



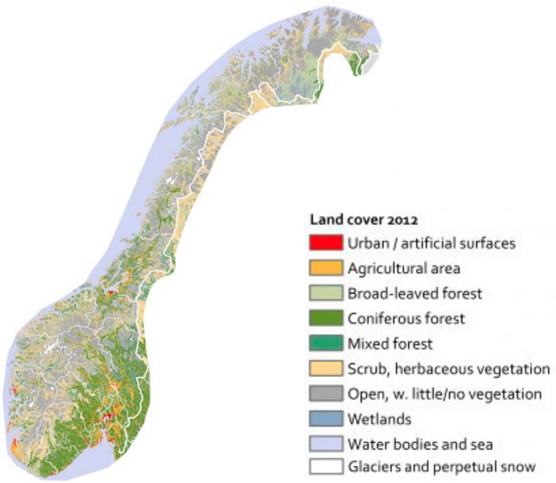




**Figure 9: (Left) Land coverage in Norway by area (Right) Map of land coverage in Norway (2012)[60,61]**

Different land areas are subject to different pressures influencing their ecological condition – wetlands are at risk of area loss and overgrowth, mountainous areas are threatened by degradation and fragmentation, and open lowlands are subject to overgrowth, intensity of farming practices, and non-native species, as summarized in Figure 10. Between 1992 and 2018, the biggest change in land cover in Norway was a loss of almost 6,000 km$^2$ of wetlands, which dried mostly due to environmental and anthropogenic causes and became forest.[62]

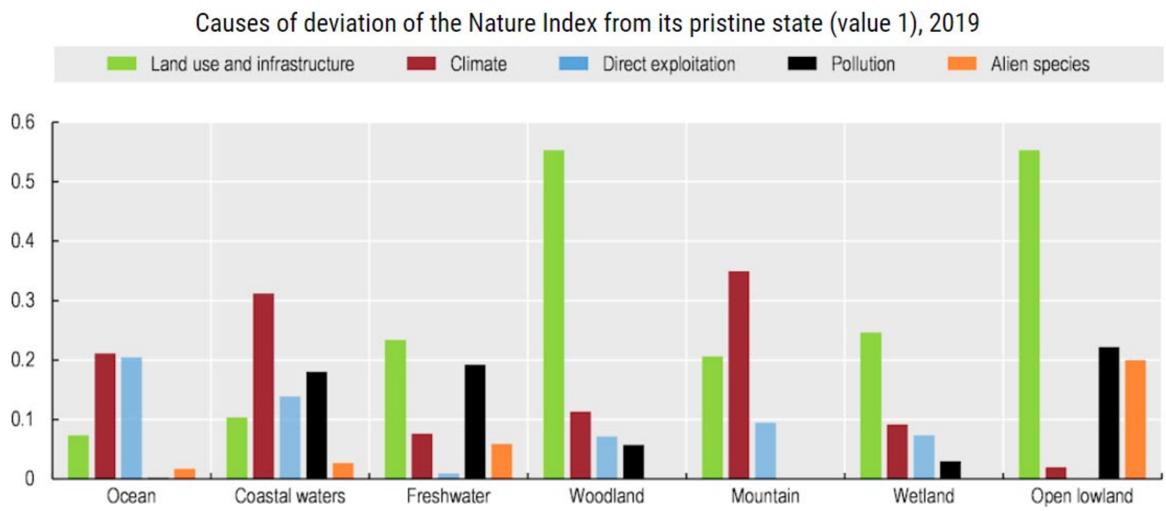



**Figure 10: Factors affecting the value of the Norwegian Environment Agency's Nature Index for land types (2022)**

57 not including Svalbard or Jan Mayen
58 Solberg, M.N. and Hestenes, S.G. (2023). *Derfor har lille Norge verdens nest lengste kystlinje.* www.nrk.no/nordland/derfor-er-kystlinjen-til-norge-lenger-enn-russland-sin-1.16309554
59 Statistisk sentralbyrå (Statistics Norway). (2023). *Construction in the coastal zone.* www.ssb.no/en/natur-og-miljo/areal/statistikk/byggeaktivitet-i-strandsonen
60 Food and Agriculture Organization. (2020). *Arable Land (% of land area) – Norway.* https://data.worldbank.org/indicator/AG.LND.ARBL.ZS?end=2020&locations=NO&start=1961&view=chart
61 Rispling, L. (2018). *Land cover 2012.* https://nordregio.org/maps/land-cover-2012/
62 Zhou, N., et al. (2021). *Overview of recent land cover changes, forest harvest areas, and soil erosion trends in Nordic countries.* https://doi.org/10.1016/j.geosus.2021.07.001

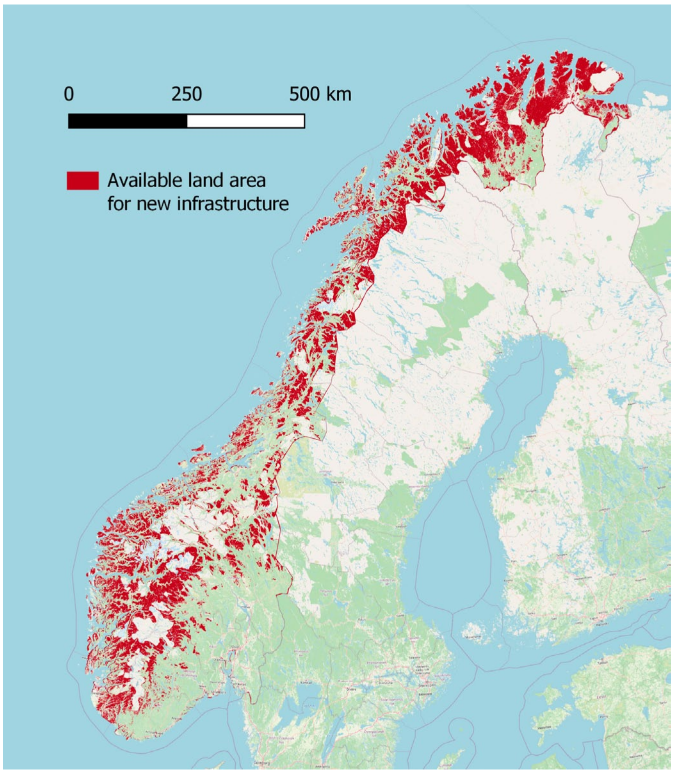



**Figure 11: Map of potential land available in Norway for CDR deployment (2023)**

Some land types are subject to protective or restorative policies. Certain outdoor areas, cultural lands, all wetlands and natural resources are protected lands, with limited infrastructure allowed in or around these areas. For example, agricultural land is regulated by the Concession Act, Allodial Act, Land Act, and Forest Act, which largely focus on the preservation of agricultural land use and operations and the enablement of private land ownership.[63] Freshwater systems, grasslands, and wetlands are areas of focus for restoration.[64]

Maps of different land types and protected areas were plotted on QGIS to assess the potential land area available for CDR deployment in Norway.

Of the 385,207 km$^2$ land area in Norway, potentially 121,731 km$^2$ could be available for new development (Figure 11). Further evaluation of this land area based on storage availability and weather conditions has been done in the subsequent sections.

## 2.4. Natural conditions in Norway

The relationship between outdoor temperature and power usage is more pronounced in Norway than in other countries. This is important in the context of CDR, especially for DACCS where the ambient temperature and humidity of the air stream drastically affects the performance of DACCS. Natural conditions are also a crucial criterion to consider for nature-based CDR solutions, such as forestry. The weather and soil conditions will affect the growth of crops, and in return, their $CO_2$ absorption abilities.

63 OECD. (2021). *Policies for the Future of Farming and Food in Norway.* https://doi.org/10.1787/20b14991-en
64 Halldórsson, G., et al. (2012). *Restoration of damaged ecosystems in the Nordic countries.* https://land.is/wp-content/uploads/2018/01/ReNo.pdf

### Temperature regime in Norway

Most of Norway has a maritime climate with mild winters and cool summers. Because of the influence of the North Atlantic Ocean, Norway has a much warmer climate than its latitudinal position would indicate. Norway's average annual temperature has increased by 1.1°C since 1900. Warming is expected to continue – under a high-emissions scenario, the projected average temperature at the end of the century is estimated to be about 4.5°C higher than it was during 1971-2000. The temperature rise is likely to be particularly marked in the northern part of the country and during winter. Warming is expected to affect energy demand, mainly by reducing consumption for heating. Summer droughts may become more severe because of increased evapotranspiration.

Several regions in Norway typically have temperatures below 0°C for long period in winters. Figure 12 shows the typical regions with this low temperature, among the land available in Norway for CDR deployment. While several other areas are also expected to have temperatures below 0°C, the area marked in the map typically has lower temperatures for longer duration in winters.[65] As specified earlier, low temperatures can be problematic for certain CDR deployment pathways such as DACCS. Further assessment on this is done in the methodology section for DACCS (Section 5.1).

For all seasons, the projections indicate a warming in Norway (Figure 13).[66] This temperature increase could impact energy demand by decreasing the number of heating degree days (HDDs). According to an assessment of climate change adaptation in Norway, milder winters will likely reduce energy demand for heating, especially in the southern part of the country.[67] However, the increase in cooling degree days (CDDs) could raise demand for cooling.

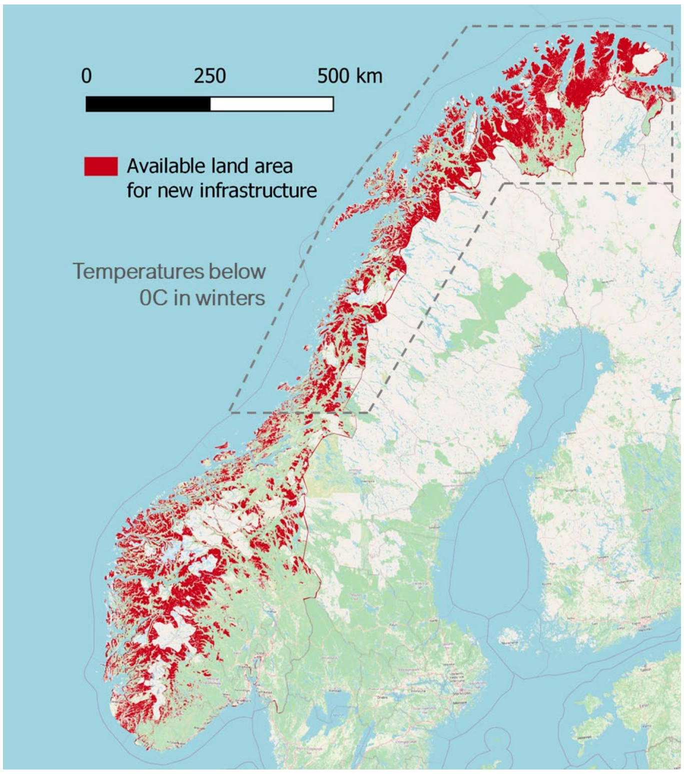



**Figure 12: Available land area in Norway for new infrastructure development, with areas with temperature below 0°C in winters for long period identified (2023)**

65 Carbon Limits Assessment using information from yr.no.
66 Hanssen-Bauer, I. et al. (2017). *Climate in Norway 2100.* www.miljodirektoratet.no/globalassets/publikasjoner/M741/M741.pdf
67 Norwegian Ministry of Climate and Environment. (2013). *Climate change adaptation in Norway.* www.regjeringen.no/contentassets/e5e7872303544ae38bdbdc82aa0446d8/en-gb/pdfs/stm201220130033000engpdfs.pdf

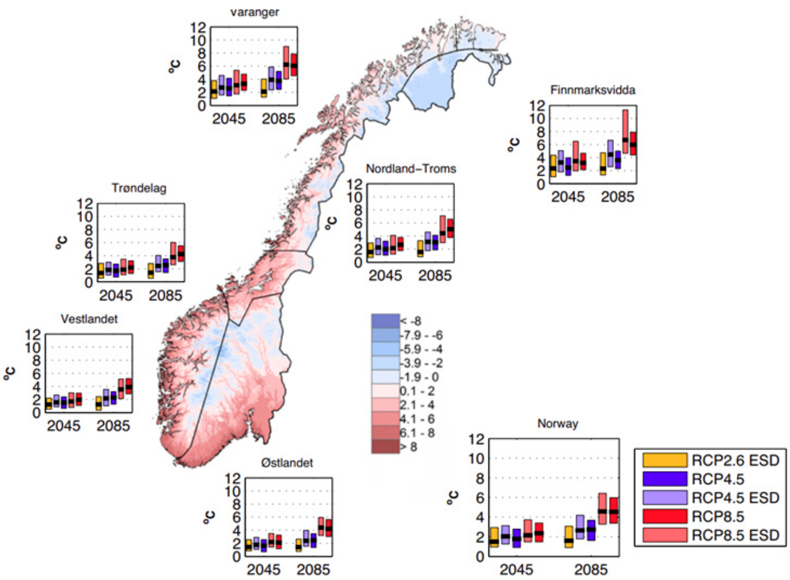
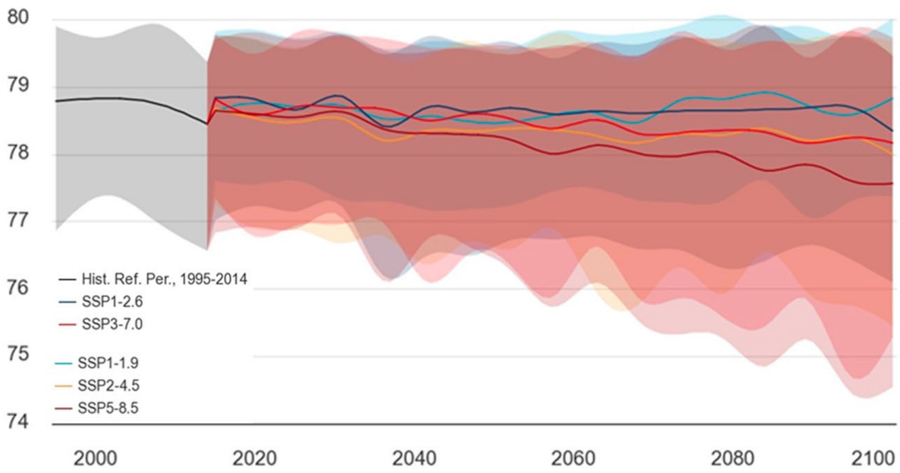



**Figure 13: Projected change in annual temperature from the period 1971-2000 to 2031-2060 (2045) and 2071-2100 (2085)[68]**

### Humidity in Norway

Norway typically has a relative humidity in the range 60 - 90%. Lowest humidity is observed in summer months, between April and July, with very high humidity (>80%) between October and February. This is an essential aspect to consider for CDR technologies such as DACCS, which can be affected by the relative humidity of the inlet air stream. It is expected that Norway will likely experience a decrease in near-surface relative humidity (Figure 14). Changes in near-surface land relative humidity are strongly influenced by evapotranspiration, which is suppressed by the drying of soils and plant responses to increasing atmospheric $CO_2$ levels.[69]




*The following changes (given as median values) are estimated in Norway by the end of this century:*

- *Annual temperature will increase by ca. 4.5 ºC (interval: 3.3 to 6.4 ºC)*
- *Annual precipitation will increase by ca. 18 % (interval: 7 to 23 %)*
- *Mean sea level will increase by 15 - 55 cm (depending on location) along the Norwegian coast*
- *Near-surface relative humidity is expected to decrease*

**Figure 14: Projected relative humidity in Norway[70]**

Natural conditions have impacts on potential deployment of CDR technologies. Certain types of DACCS technologies, such as mineral looping DACCS, are dependent on the humidity levels being within a range for ideal operation (see Section 5.1).[71] However, given that the humidity levels are typically high in Norway, the expected decrease in humidity will not affect the CDR deployment potential.

68 Hanssen-Bauer, I. et al. (2017). *Climate in Norway 2100.* **www.miljodirektoratet.no/globalassets/publikasjoner/M741/M741.pdf**
69 Climate Change Knowledge Portal. (n.d.) *Climate Projections: Mean Projections.* **https://climateknowledgeportal.worldbank.org/country/norway/climate-data-projections**
70 Hanssen-Bauer, I. et al. (2017). *Climate in Norway 2100.* **www.miljodirektoratet.no/globalassets/publikasjoner/M741/M741.pdf**
71 Lower humidity conditions allow for better interaction between the $CO_2$ in the air and the sorbent material, aiding in the absorption of $CO_2$ from the atmosphere.

## 2.5. Biomass feedstock availability in Norway

Norway uses biomass in a range of industrial sectors, including waste-to-energy (energy in the form of heat and biofuels), chemicals and cement, pulp and paper, and biomethane.[72,73] This section details the primary biomass feedstocks in Norway and associated processes. The emissions from biomass-related incineration / fermentation activities can be classified as "Bio-$CO_2$". When captured and stored, this can help with $CO_2$ removals from the atmosphere. Knowing the location and volume of the emissions and distance from storage sites would be important parameters to consider when assessing the Bio-CCS potential in Norway.

### Wood

Norway's primary biomass feedstock is woody biomass produced from the country's ample forested areas. Most woody biomass produced in Norway is used for manufacturing pulp, paper, and wood products, and approximately 20% is used for energy production.[74] In 2021, 11.5 million cubic meters (mcm) of timber were harvested and used for various industrial processes.[75] It is estimated that up to 15 mcm can be harvested sustainably each year.[76]

### Organic waste

Organic wastes, including municipal waste, wood waste, and to a lesser extent agricultural residues, are another one of Norway's main biomass feedstocks. Organic waste also includes sludges which, though they often contain some inorganic waste materials, are often used as organic feedstocks for processes like biogas production, composting, incineration, or material recovery.[77]

Norway produced 2.36 million tonnes (Mt) of biomass waste in 2021, with the breakdown of sources depicted in Figure 15 (a). Of these sources, wood waste, paper and cardboard waste, and "wet organic waste" dominate. "Wet organic waste" is often waste related to food disposal or manufacturing. Nearly 50% (212,000 t) of this category was generated by households, while 200,000 t were generated by manufacturing or service industries.[78]

In 2021, 30% of Norway's organic waste was incinerated and 14% was used for biogas production.[79] Nearly 50% was sent to material recovery or composting. Compost produced in Norway is generally allocated to agricultural land or used to make various soil products, such as bioroofs, soil mixtures, and pellets.[80] Animal byproducts, primarily manure and fish farming residues, are another form of organic waste used to generate energy for industrial purposes or to create biogas. Figure 15 (b) illustrates the amount of animal byproducts used to produce biogas and for compost in 2020.

In 2017, several ministries and sector organizations in Norway signed an agreement to reduce food waste by 50% by 2030. This is in line with UN's sustainable development goal 12.3. The agreement covers the whole value chain, from primary production to the retail sector, including making a push for reduction of wastes from households.[81] This will reduce the wet organic waste and waste from animal byproducts generated in Norway.

72 Norske utslipp. (n.d.). *Utslipp til luft i Norge.* www.norskeutslipp.no/no/Komponenter/Utslipp/Karbondioksid-biomasse/?ComponentType=utslipp&ComponentPageID=179
73 IEA Bioenergy. (2021). *Implementation of bioenergy in Norway – 2021 update.* www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_Norway_final.pdf
74 Hamilton, R. (2019). *The Role of Biomass in Norway's Energy Mix.* www.sum.uio.no/include/publikasjoner-media/sommerstudier/2019/the-role-ryan-hamilton.pdf
75 Helseth, E.V., et al. (2022). *Forest ecosystem services in Norway: Trends, condition, and drivers of change (1950–2020).* https://doi.org/10.1016/j.ecoser.2022.101491
76 Center for International Climate Research (CICERO). (2021). *Forest-based bioenergy in Norway's green transition: Balancing production and other societal interests.* https://pub.cicero.oslo.no/cicero-xmlui/bitstream/handle/11250/2834949/Report%202021%2009%20web.pdf?sequence=1&isAllowed=y
77 Statistisk sentralbyrå (Statistics Norway). (2022). *Waste accounts.* www.ssb.no/en/natur-og-miljo/avfall/statistikk/avfallsregnskapet
78 Scarlat, N., et al. (2011). *An overview of the biomass resource potential of Norway for bioenergy use.* DOI: 10.1016/j.rser.2011.04.028
79 Scarlat, N., et al. (2011). *An overview of the biomass resource potential of Norway for bioenergy use.* DOI: 10.1016/j.rser.2011.04.028
80 Ålund, I., et al. (2021). *Behandling og disponering av avløpsslam og annet organisk avfall i Norge (M-2155 I 2021; p. 45).* www.miljodirektoratet.no/publikasjoner/2021/desember-2021/behandling-og-disponering-av-avlopsslam-og-annet-organisk-avfall-i-norge/
81 One Planet Network. (2023). *The Norwegian Voluntary Agreement on Reduction of Food Waste.* www.oneplanetnetwork.org/knowledge-centre/policies/norwegian-voluntary-agreement-reduction-food-waste

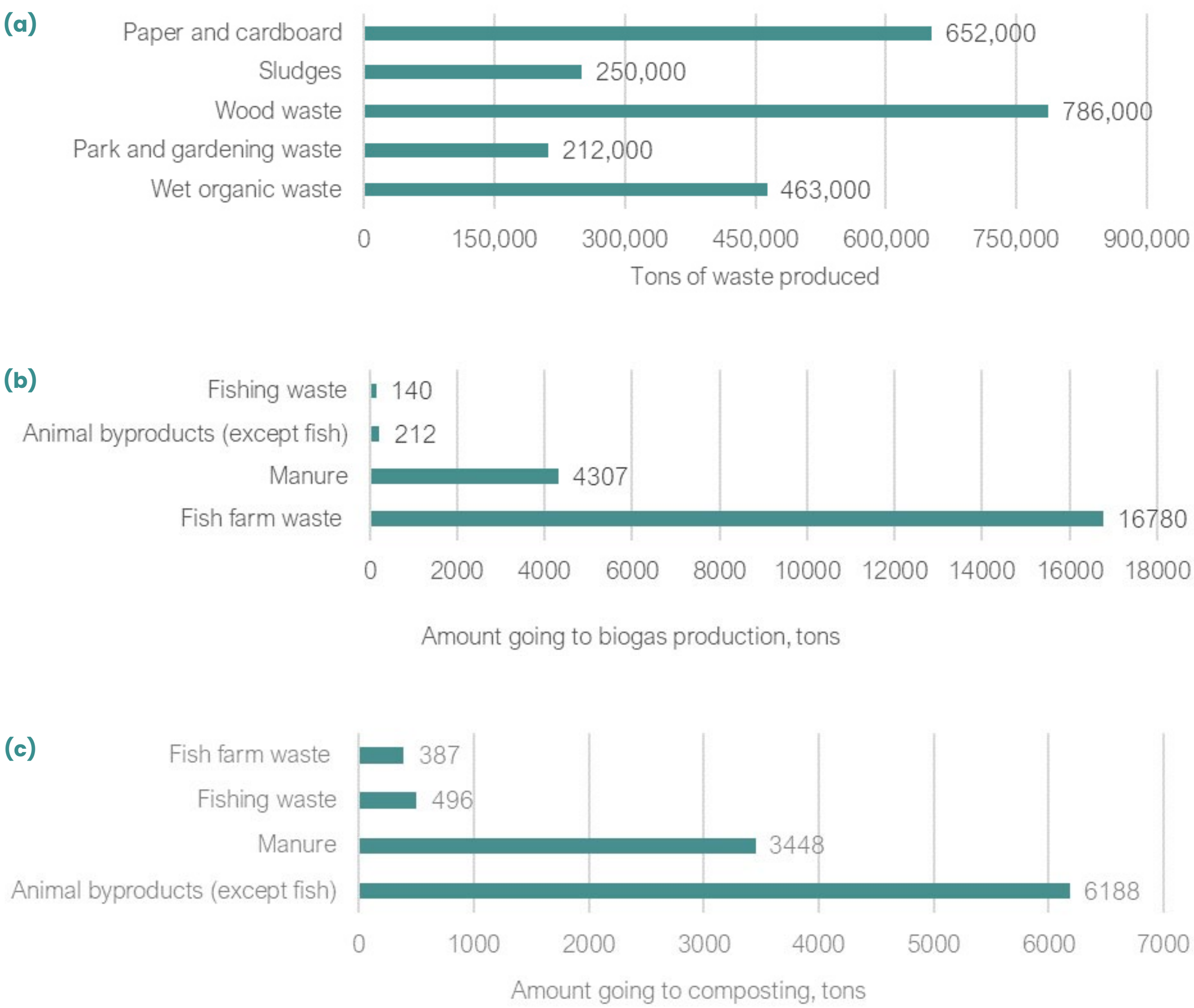



**Figure 15: (a) Waste biomass produced (2021) (b) Animal byproducts used in biogas production (2020) (c) Animal byproducts composted (2020)**[82]

### Purpose-grown feedstocks

Energy crops, which are crops grown for the sole purpose of producing bioenergy, are not a significant source of biomass in Norway. Scarlat et al. (2011) estimated the production potential of energy crops in Norway to be between 3.5 – 11 PJ in 2011; by contrast, the energy potential from the forest sector was estimated to be between 88 – 124 PJ.[83] Today, energy crops are still not an important renewable energy resource in the country, which places a higher focus on hydropower resources.[84] The prominence of woody biomass in Norway and the lack of available agricultural land are likely factors explaining why energy crop use is not more widespread in the country.[85]

Purpose-grown algae is a relatively new endeavour of the Norwegian aquaculture industry – the first licenses were granted in 2014. In 2022, 221 t of algae were sold in Norway, mainly for use in cosmetics, pharmaceuticals, and food products.[86]

82 Statistisk sentralbyrå (Statistics Norway). (2022). *Waste accounts.* www.ssb.no/en/natur-og-miljo/avfall/statistikk/avfallsregnskapet
83 Scarlat, N., et al. (2011). *An overview of the biomass resource potential of Norway for bioenergy use.* DOI: 10.1016/j.rser.2011.04.028
84 Støa, P., et al. (2019). *Energi og Industri: Mulighetsrom verdikjeder. NHO Veikart for fremtidens næringsliv.* www.nho.no/contentassets/998441bd312b471e964a6d9ea022afe8/sintef-rapport-2019_01139_energi-og-industri.pdf
85 Norsk Fjernvarme. (n.d.). *Om energikildene.* www.fjernkontrollen.no/content/om-energikildene/
86 Fiskeridirektoratet (Directorate of Fisheries). (2023). *Høsting av alger til konsum og fôr. Mengde i tonn. Verdi i 1000 kroner.* dub.sh/FFSA3LW

### Future biomass potential in Norway

A 2019 report for Nordic Energy Research suggests that the availability of forest biomass for bioenergy is not expected to increase in the future due to land use restrictions, conservation efforts, and a heavier emphasis on other energy sources.[87] Similarly, because national policies currently do not promote or facilitate the production of energy crops, it is unlikely that their sector will grow significantly in the near future.

However, the Norsk Industri's roadmap for decarbonizing the process industry does talk about the potential to increase wood harvesting (sustainably) in Norway from the current harvesting level of 10 mcm to up to 15 mcm each year.[88] Norsk Industri emphasises the importance of assessing the best use of available biomass and enabling policies that will increase access to wood through sustainable value chains from the forest.[89]

Table 6 summarises current and future biomass feedstock availability estimates based on data from studies by Carbon Limits[90] and SINTEF256, respectively. More detail on these studies can be found in Annex 4. The Table shows the biomass potential estimated in the SINTEF paper to be very high. Several aspects such as political conditions enabling this level of feedstock collection, accessibility of these feedstocks and the economic viability of the collection process must be considered to estimate a realistic potential. While the potential to achieve this scale by 2030 will be challenging, the estimates provide a reasonable target for achieving it by 2040 – 2050.

| Sector | Feedstock | 2030 (kt) (CL) | 2020 (kt) (SINTEF) | 2030 (kt) (SINTEF,BAU) | Increment (2020-2030) (SINTEF, BAU) |
|---|---|---|---|---|---|
| Agriculture | Livestock manure | 859 | 4016 | 4145 | 0.3% p.a. |
| | Straw | 600 **a** | 169 | 174 | 0.3% p.a. |
| Forestry | Timber to non-energy products (incl. Export) | - | 0 | 0 | 2.8% p.a. |
| | Bark | - | 704 | 898 | 2.8% p.a. |
| | Timber-processing residues and logs | - | 1060 | 1357 | 2.8% p.a. |
| | Residues from urban expansion | - | 331 | 354 | 2.8% p.a. |
| | Branches and tops | - | 3207 | 4104 | 2.8% p.a. |
| | Stumps and roots | - | 0 | 0 | 2.8% p.a. |
| Marine | Macroalgae | - | 0 | 0 | 50.0% p.a. |
| Waste | Wood waste | - | 552 | 661 | 2.0% p.a. |
| | Sewage sludge | 133 | 608 | 652 | 0.7% p.a. |
| | Fish waste | - | 157 | 157 | 0% p.a. |
| | Fish silage | 125 | 30 | 39 | 2.0% p.a. |
| | Fish sludge | 20 **b** | 126 | 168 | 4.0% p.a. |
| | Wet organic waste from households | 318 **c** | 220 | 234 | 0.7% p.a. |
| | Wet organic waste from industry | 63 | 169 | 181 | 0.7% p.a. |
| | Mixed waste to Waste-to-Energy | 210 **d** | 1080 | 1080 | 0% p.a. |
| | Exported waste | - | 0 | 0 | 1.0% p.a. |

**a** Includes agricultural residue of straw and grain cleaners. **b** presented as fish slime in Carbon Limits (CL) report
**c** Presented as food waste in CL report. **d** Includes (1) Food waste: wholesalers, grocery stores (2) Food waste: catering industry (3) Used cooking oil (UCO) and (4) vegetable and fruit scraps

**Table 6: Current biomass feedstock available and projection of feedstock available in 2030 by Carbon Limits and SINTEF.[91,92]**

87 Pöyry Management Consulting Oy. (2019). *Potential for bioenergy in the Nordics.* www.nordicenergy.org/wordpress/wp-content/uploads/2019/01/Nordic_Bioenergy_Potential_P%C3%B6yry_Final-Report.pdf
88 Center for International Climate Research (CICERO). (2021). *Forest-based bioenergy in Norway's green transition: Balancing production and other societal interests.* https://pub.cicero.oslo.no/cicero-xmlui/bitstream/handle/11250/2834949/Report%202021%2009%20web.pdf?sequence=1&isAllowed=y
89 Norsk Industri. (2016). *Veikart for prosessindustrien – økt verdiskaping med nullutslipp i 2050.* www.norskindustri.no/siteassets/dokumenter/rapporter-og-brosjyrer/veikart-for-prosessindustrien_web.pdf
90 Isakova, I., et al. (2019). *Ressursgrunnlaget for produksjon av biogass i Norge i 2030: Sammenfatning av kunnskap og oppdaterte analyser.* Carbon Limits.
91 Isakova, I., et al. (2019). *Ressursgrunnlaget for produksjon av biogass i Norge i 2030: Sammenfatning av kunnskap og oppdaterte analyser.* Carbon Limits.
92 Carbon Limits analysis using information from SINTEF paper: Everson, N. et al. (2023). *What is the potential of BioCCS to deliver negative emissions in Norway? From biomass mapping to a window of negative emissions potential.* https://psecommunity.org/LAPSE:2023.36828

## 2.6. Mineral feedstock availability in Norway

Norway does not currently have comprehensive public data on total estimated available mineral resources in the country. However, the national mineral strategy released in June 2023 identifies five focus areas for the sector, including an aim to improve project timelines and efficiency, which will partly be achieved through improved mineral resources mapping and project planning.[93] An overview of minerals sold in Norway in 2021 is presented in Figure 16.[94]

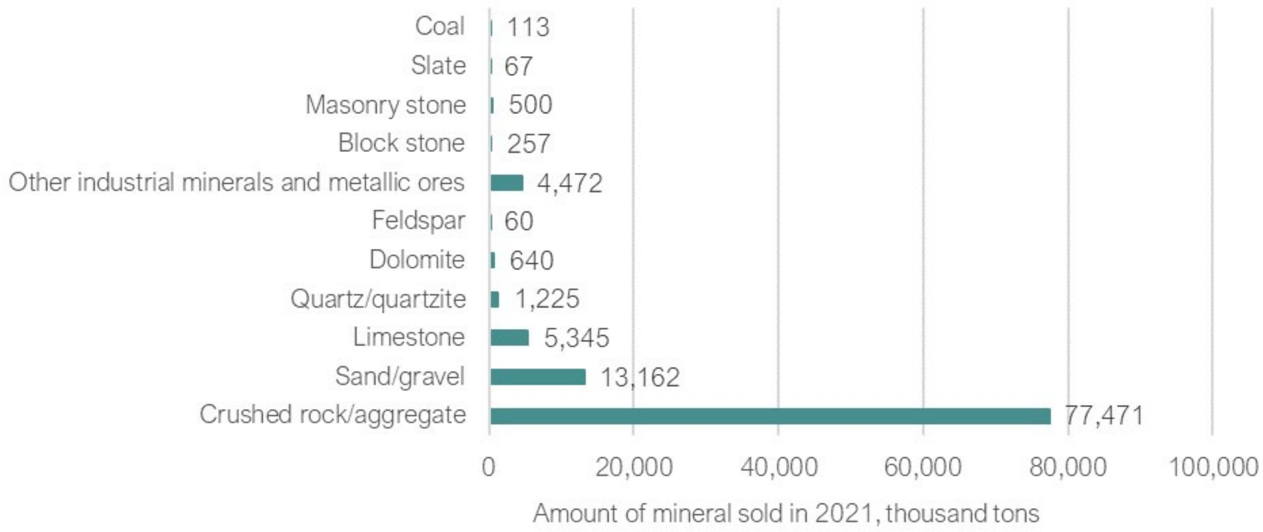



**Figure 16: Mineral resources sold in Norway in 2021[95]**

Olivine, a silicate mineral that may be categorized under "Other industrial minerals and metallic ores" in Figure 16, is an important resource for carbon removal technologies like terrestrial and coastal enhanced weathering. Norway likely has the largest olivine reserves in the world – the country is responsible for up to half of global production.[96]On average, Norway's annual olivine production capacity stands at around 1 Mtpa, but production can reach up to 3 Mtpa in periods of high demand.[97] Olivine is mined from dunite deposits, which are mostly concentrated in Sunnmøre and Nordfjord.[98] Olivine locations, as determined by NGU, are shown in Figure 17.

Dolomite is a carbonate mineral that can be used in ocean alkalinization technologies. As presented in Figure 16, 0.64 Mt of dolomite were sold in Norway in 2021, but it is estimated that up to 1 Mt of the mineral are produced in Norway each year.[99] Dolomite is currently mined in Sørfold, Fauske, Vefsn and Ballangen. Limestone, which is also important in ocean alkalinization, can be found in Norway in offshore sediment basins. It can also be found in a lightly metamorphosed form in the Oslofeltet, a geologic region extending north of Oslo to Brumunddal and south to Langesund.[100,101,102] Approximately 5.3 Mt of limestone were sold in Norway in 2021. Limestone and marble locations in Norway are illustrated in Figure 17.

93 Nærings- og fiskeridepartementet (Ministry of Trade, Industry, and Fisheries). (2023). *Norwegian Mineral Strategy.* **www.regjeringen.no/contentassets/1614eb7b10cd4a7cb58fa6245159a547/norges-mineralstrategi_engelsk_uu.pdf**
94 Direktoratet for mineralforvaltning (Directorate of Mining). (2022). *Harde fakta om mineralnæringen 2021.* **https://dirmin.no/sites/default/files/harde_fakta_-_oppslag.pdf**
95 Direktoratet for mineralforvaltning (Directorate of Mining). (2022). *Harde fakta om mineralnæringen 2021.* **https://dirmin.no/sites/default/files/harde_fakta_-_oppslag.pdf**
96 Norge Geologiske Undersøkelse (NGU). (n.d.). *Olivin.* **www.ngu.no/geologiske-ressurser/olivin**
97 Interview with Sibelco
98 Store norske leksikon. (2020). *Olivin.* **https://snl.no/olivin**
99 Store norske leksikon. (2023). *Dolomitt.* **https://snl.no/dolomitt**
100 Norge Geologiske Undersøkelse (NGU). (n.d.). *Kalkstein.* **www.ngu.no/om-geologi/kalkstein**
101 Store norske leksikon. (2020). *Kalkstein.* **https://snl.no/kalkstein**
102 Store norske leksikon. (2023). *Oslofeltet.* **https://snl.no/Oslofeltet**

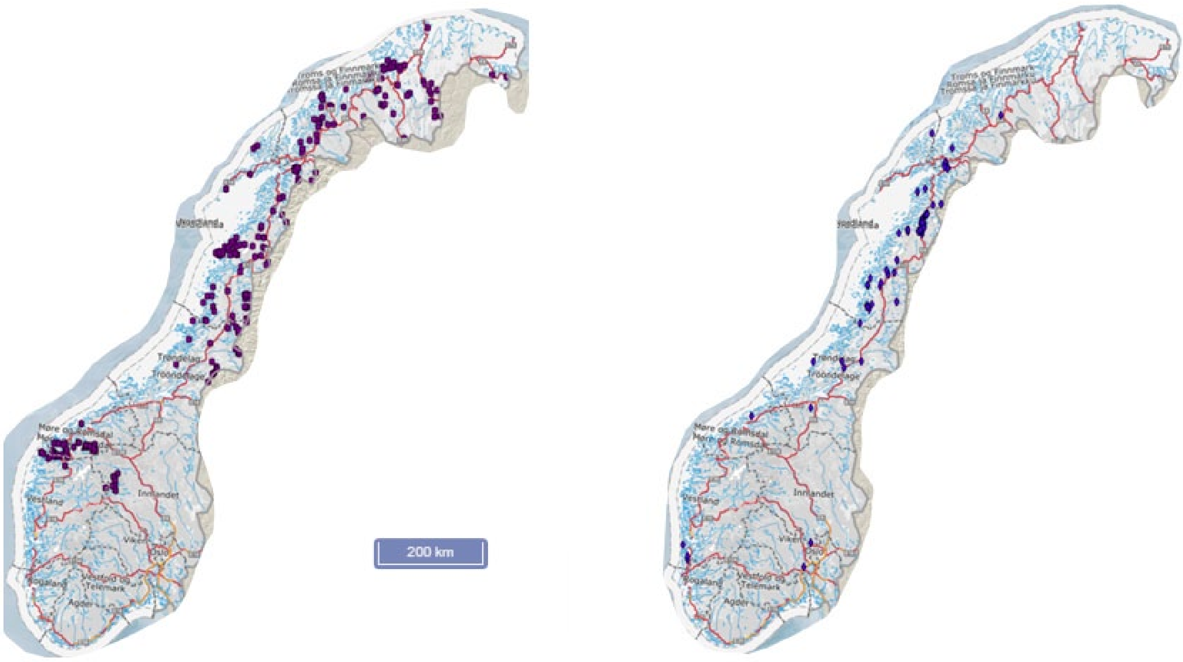



**Figure 17: (Left) Olivine reserves in Norway. (Right) Limestone and marble reserves in Norway**[103]

Large amounts of basalt were deposited in Norway millions of years ago, both on- and offshore. It can be found in places such as the Krokskogen forest, the municipalities of Holmestrand, Bømlo, Karmøy, and Lyngen, and the geologic regions of Bergensfeltet and Trondheimsfeltet.[104] Over 100 basalt flows have also been identified in the Norwegian Sea.[105] However, estimates on the quantity of reserves are yet to be done.

The five focus areas of Norway's national mineral strategy also include an aim to strengthen the industry, particularly in global climate-related value chains, through international cooperation. This indicates an ambition to further develop the industry around minerals related to carbon removals.

## 2.7. $CO_2$ transport and storage potential in Norway

One of the predominant assessments required for DACCS and bio-CCS potential in a country is the estimation of the $CO_2$ storage potential in or around the country. $CO_2$ can be stored in several underground formations and in basalt. There is considerable $CO_2$ storage capacity in offshore deep saline aquifers and depleted oil and gas reservoirs in Norway. A major part of the European storage capacity is to be found in sedimentary basins on the Norwegian continental shelf.[106]

### $CO_2$ storage in geological formations

Storage capacity estimates on the Norwegian continental shelf are significant and range from 29 $GtCO_2$ to 86 $GtCO_2$.[107,108] For example, SINTEF estimates that if 10% of the storage capacity is used, it would be possible to store about 40 years' worth of carbon emissions from the European cement industry.[109] While the Norwegian mainland has no deep saline aquifers suitable for $CO_2$ storage, there is an untapped potential for mineral carbonation (ultramafic/mafic rocks, anorthosite).

**103** Norge Geologiske Undersøkelse (NGU). (n.d.). *Mineralressurser - Industrimineraler, metaller og naturstein.* **https://geo.ngu.no/kart/mineralressurser_mobil/**
**104** Store norske leksikon. (2020). *Basalt.* **https://snl.no/basalt**
**105** Kjølhamar, B., et al. (2021). *New approaches to CCS.* DOI: 10.3997/1365-2397.fb2021043.
**106** Anthonsen, K.L. et al. (2012). *$CO_2$ storage potential in the Nordic region.* **www.sintef.no/globalassets/sintef-energi/nordiccs/d-6.1.1205-2-co2-storage-potential-in-the-nordic-region_web.pdf**
**107** EU GeoCapacity Project. (n.d.). *GeoCapacity.* **www.geology.cz/geocapacity**
**108** Norwegian Petroleum Directorate. (n.d.). *$CO_2$ Atlas for the Norwegian Continental Shelf.* **www.npd.no/en/facts/publications/co2-atlases/co2-atlas-for-the-norwegian-continental-shelf/**
**109** Gassnova. (2023). *Safe carbon storage.* **https://gassnova.no/en/news/safe-carbon-storage**

The Norwegian Petroleum Directorate (NPD) evaluated storage capacity of aquifers and oil and gas fields in the North Sea, Norwegian Sea and southern Barents Sea. Results are presented in Table 7 below. As seen from the Table, the aquifers in the North Sea and Norwegian Sea belong to areas where conflicts of interests with the petroleum industry are unlikely – thus, most of these areas were categorised as "green" in terms of maturity. However, most parts of the southern Barents Sea were of interest for future petroleum exploration – consequently the studied aquifers are indicated in blue.

The "Data quality" column in Table 7 indicates the amount of data available for potential storage sites. Most areas that have been recently explored by the petroleum industry are covered by 3D seismic data (indicated in green). Aquifers with few well penetrations, and mainly 2D seismic coverage, are indicated in orange. Meanwhile those with only 2D seismic or sparse data are indicated in red. In general, data coverage of the studied aquifers is sparse, as they belong to provinces which are less attractive for the petroleum industry. More data would have to be acquired if such aquifers are selected for maturation of possible storage sites.

Figure 18 illustrates $CO_2$ storage capacity on the Norwegian continental shelf, as well as existing and planned $CO_2$ storage projects. Norway has extensive experience with $CO_2$ storage in geological formations. There are two existing storage sites located at the Sleipner and Snøhvit oil and gas fields. More than 20 $MtCO_2$ from the Sleipner Vest field are now stored in the Utsira Formation in the North Sea. Every year since 1996, 1 $MtCO_2$ have been captured from natural gas production at the field and stored in an aquifer.[110] $CO_2$ storage at the Snøhvit Field started in 2008 and is also located in a deep saline aquifer. $CO_2$ is injected at a rate of 0.7 Mt annually in water-saturated sandstone reservoirs under the Snøhvit Field in the Barents Sea.

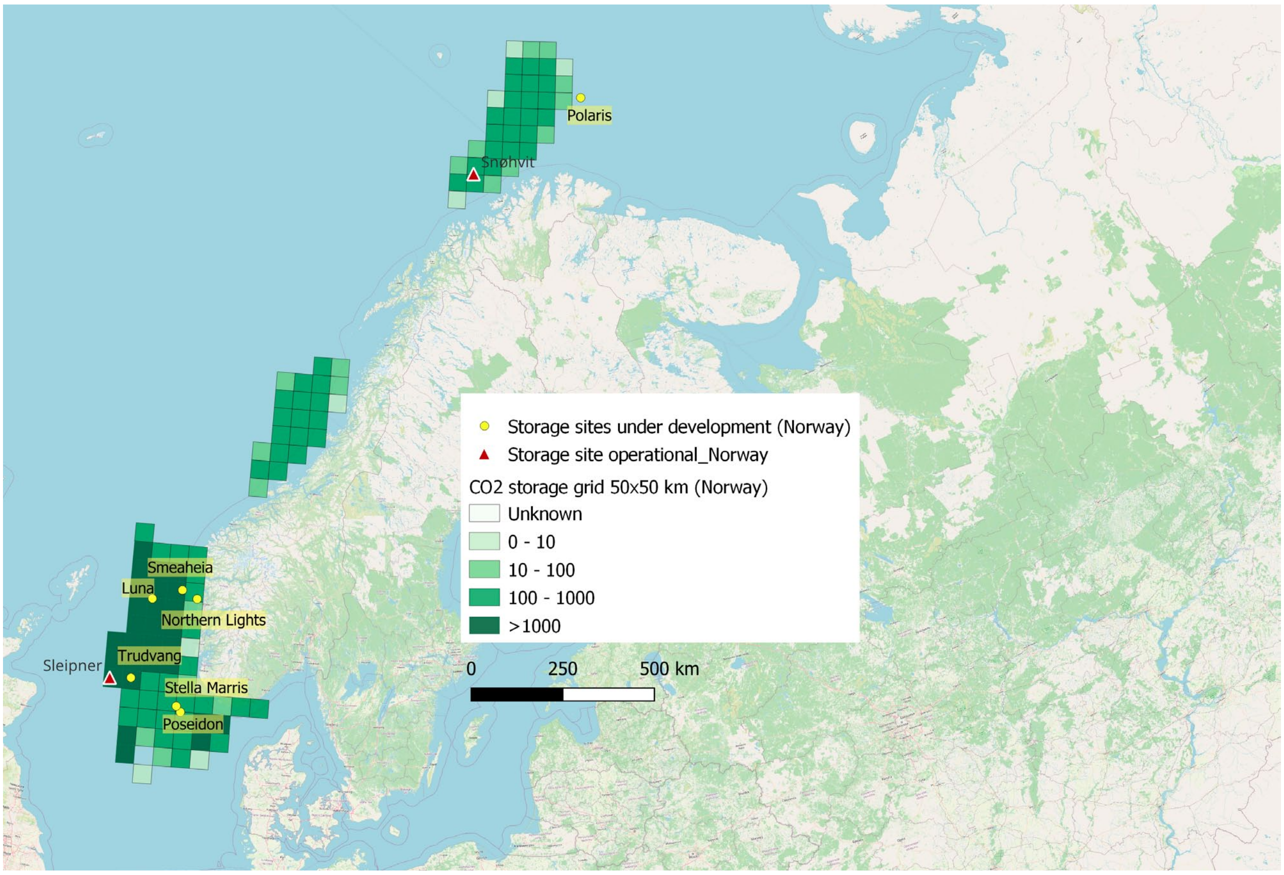



**Figure 18: Overview of $CO_2$ storage potential and activities in Norway[111]**

110 Gjeldvik, Ine T. et al. (2014). *$CO_2$ storage in the Utsira-Skade aquifer.* www.npd.no/globalassets/1-npd/fakta/co-to/poster-co2storage-utsira-skade-aquifer-eage-2014-stavanger.pdf
111 Carbon Limits, 2024

| Aquifer | Capacity Gt | Injectivity | Seal | Maturity | Data quality |
|---|---|---|---|---|---|
| **North Sea aquifers** | | | | | |
| Utsira and Skade Formations | 15,8 | 3 | 2 | | |
| Bryne and Sandnes Formations | 13,6 | 2 | 2/3 | | |
| Sognefjord Delta East | 4,1 | 3 | 2/3 | | |
| Statfjord Group East | 3,6 | 2 | 3 | | |
| Gassum Formation | 2,9 | 3 | 2/3 | | |
| Farsund Basin | 2,3 | 2 | 2/3 | | |
| Johansen and Cook Formations | 1,8 | 2 | 3 | | |
| Fiskebank Formation | 1 | 3 | 3 | | |
| **Norwegian Sea aquifers** | | | | | |
| Garn and Ile Formations | 0,4 | 3 | 3 | | |
| Tilje and Åre Formations | 4 | 2 | 2/3 | | |
| **Barents Sea aquifers** | | | | | |
| Realgrunnen Subgroup, Bjarmeland Platform | 4,8 | 3 | 2 | | |
| Realgrunnen Subgroup, Hammerfest Basin | 2,5 | 3 | 2 | | |
| | | | | | |
| | | | | | |
| **Evaluated prospects** | | | | | |
| North Sea | 0,44 | | | | |
| Norwegian Sea | 0,17 | | | | |
| Barents Sea | 0,52 | | | | |
| | | | | | |
| | | | | | |
| **Abandoned fields** | | | | | |
| **North Sea** | 3 | | | | |
| | | | | | |
| **Producing Fields_2050** | | | | | |
| North Sea 2050 | 10 | | | | |
| North Sea_Troll aquifer | 14 | | | | |
| | | | | | |
| Norwegian Sea | 1,1 | | | | |
| | | | | | |
| Barents Sea | 0,2 | | | | |

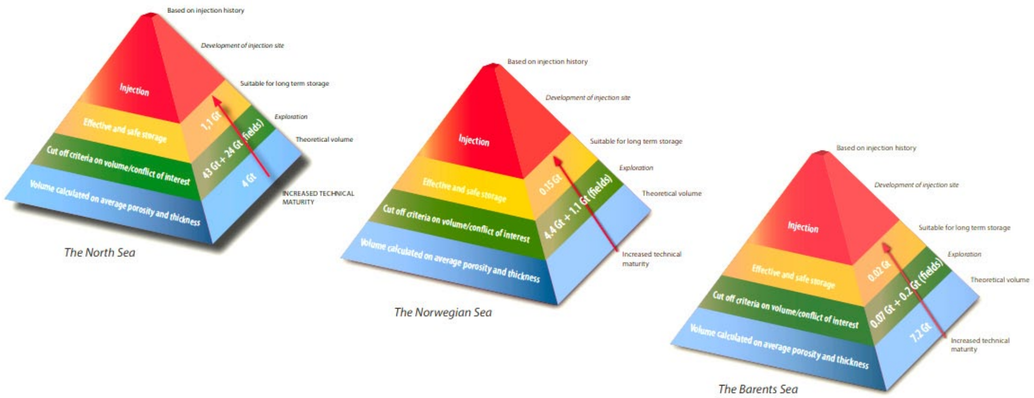



**Table 7: An overview of $CO_2$ storage capacity on the Norwegian shelf[112]**

The legend at the bottom depicts the different maturity stages of the storage sites. This includes (Stage 1) stores for which theoretical volumes have been calculated based on porosity and thickness (blue), (Stage 2) stores for which volume has been calculated by removing any conflicts of interest with the petroleum industry (green), (Stage 3) stores where the trap, reservoir, and seal have been evaluated against technical and regulatory criteria (orange), and (Stage 4) stores into which $CO_2$ is being/has been injected (red).

**112** $CO_2$ atlas for Norwegian continental shelf

As of September 2023, the Ministry of Petroleum and Energy has granted seven permits under the $CO_2$ storage regulations.[113] These sites are indicated in yellow in Figure 18. More information about these $CO_2$ storage projects is presented in Table 8.

| Project | Developer | Type of storage | Status | Capacity (Mtpa) | Available capacity* (Mtpa) | Start of operation |
|---|---|---|---|---|---|---|
| **Northern Lights** | Shell, Total, Equinor, Northern Lights JV DA, Climeworks | Deep saline aquifer | Under construction. Operating license issued. | 1.5-5 – 10 | 1 | 2024-2026 – 2030 |
| **Luna** | Wintershall, CapeOmega | Deep saline aquifer | Exploration permit issued | 5 | 5 | ? |
| **Stella Maris** | Wintershall, Altera Infrastructure | Deep saline aquifer | Exploration permit issued in 2023 | 7 | ? | ? |
| **Smeaheia** | Equinor | Deep saline aquifer | Exploration permit issued | 20 | 20 | 2028 |
| **Trudvang** | Sval Energi, Storegga, Neptune Energi | Deep saline aquifer | $CO_2$ storage licence awarded | 9 | 9 | 2029 |
| **Poseidon** | Aker BP/ OMV (Norge) / Höegh LNG | Deep saline aquifer | Exploration permit issued in 2023 | 5 | ? | 2030 |
| **Polaris** | Horisont Energi, (Vår Energi, Equinor until June 2023) | Deep saline aquifer | Exploration license – subsurface studies in progress | 2 | 0 | ? |

*Available capacity means the capacity not yet under contracts for others

**Table 8: Overview of planned $CO_2$ storage projects in Norway[114]**

The combined storage capacity of upcoming $CO_2$ storage projects in Norway, as illustrated in Figure 19, is projected to reach 58 million tonnes per annum (Mtpa) by 2030. It is important to note that only 23 Mtpa of this capacity has been reserved by the planned $CO_2$ capture projects, leaving 35 Mtpa of storage capacity available for future allocation.

113 Norsk Petroleum. (2023). *Carbon Capture and Storage.* www.norskpetroleum.no/en/environment-and-technology/carbon-capture-and-storage/
114 Carbon Limits Assessment, based on several sources, 2023

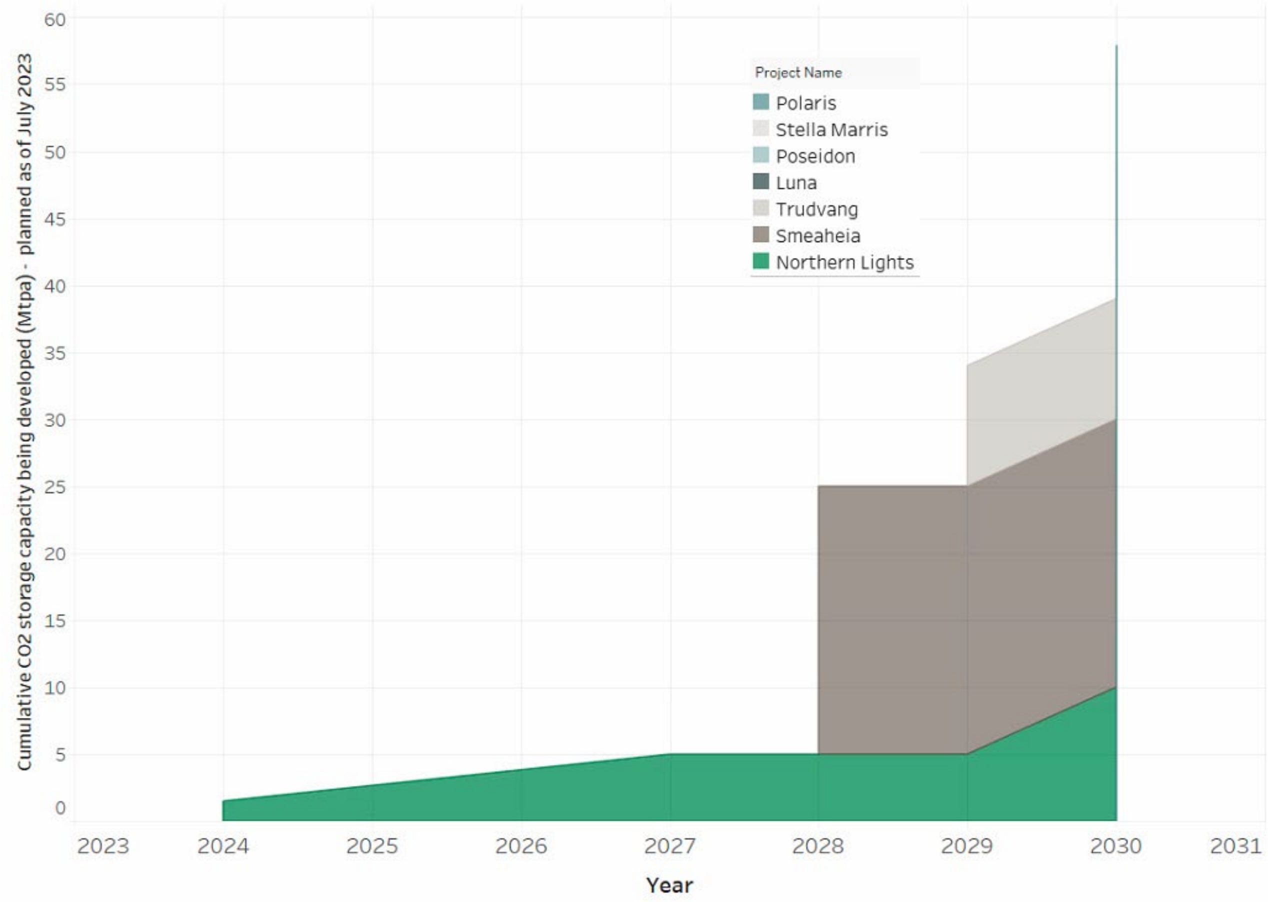



**Figure 19: Cumulative storage capacity of planned $CO_2$ storage projects in Norway[115]**

## $CO_2$ transport assessment in Norway

$CO_2$ can be transported by truck, train, barge, ship and pipeline. As presented in Table 9, train and truck transport are relevant for small volumes (or approximately 1,000 $tCO_2$ in total per train). They are usually used on short to medium distance transport and can reach higher travelling speeds than other means of transport. Barge transport is used on rivers and ship transport on open waters. Both have a medium capacity (this could grow for ships in the coming years) and can be used on medium (barge) to long (ship) distances. Pipeline transport is the mode offering the widest range of volume and distance. On the other hand, it is less flexible than other types of transport due to its static localization which will not allow to switch provider or destination.

| Mode of transport | Approx. transport capacity ($tCO_2$) | Speed (km/h) | Usual distance |
|---|---|---|---|
| **Train** | 1,000 per train (~20 wagons) | 60 | Short – Medium |
| **Truck** | 20 – 30 | 90 | Short |
| Barge | 6,500 | 18.5 | Medium |
| **Pipeline** | - | 18-36 | Short – Long |
| Ship | + 12,000 | 33 | Medium – Long |

**Table 9: Properties of $CO_2$ transport modes[116]**

**115** Carbon Limits, 2023
**116** Carbon Limits, 2023

Currently Norway does not have an established $CO_2$ transport network. There is only one 153 km long $CO_2$ pipeline that transports $CO_2$ from LNG processing plant to an offshore injection site at Snøhvit gas field. The location of the pipeline is presented in Figure 20.

Transportation of both $CO_2$ and biomass (especially wet) is seen as a significant challenge in Norway due to the size of the country, small roads and distance between the different sources of $CO_2$ and biomass.

Despite the limited $CO_2$ transport network today, Norway has significant growth potential in this field.

Most of the planned CCS projects in Norway are building their infrastructure from the ground up. In some cases, depending on project specification, it will be possible to repurpose the existing oil and gas infrastructure for $CO_2$ transport. Also, existing transportation networks can be integrated into CCS hubs, serving as entry and exit points for $CO_2$ transport. The hubs can act as central points for managing and optimizing $CO_2$ logistics, including the following aspects.

**Road networks.** Norway has an extensive network of roads that connect various regions of the country and neighbouring Sweden and Finland. These roads can serve as transport routes for captured $CO_2$. Tanker trucks or other specialized vehicles can transport $CO_2$ from industrial capture sites to CCS hubs or other purpose-built infrastructure. If a new $CO_2$ transport project significantly increases the burden on the existing road network, it may be necessary to build a dedicated road exclusively for that project.


**Figure 20: Map showing the location of the Snøhvit Field, the $CO_2$ pipeline and the Melkøya terminal**

**Rail networks.** Rail transport may be suitable for larger quantities of $CO_2$ and for connecting remote industrial sites to the hubs. However, it is important to note that railway infrastructure capacity is limited, and its further development is both expensive and time-consuming.

**$CO_2$ shipping.** Norway's extensive coastline provides opportunities for marine transport of $CO_2$. It also presents abundant opportunities for establishing additional CCS hubs that incorporate ships as a transportation method. Coastal shipping and short sea shipping can be employed to transport $CO_2$ to and from industrial sites, storage hubs, or international export.

**Pipeline infrastructure.** In some cases, it is possible to retrofit existing pipelines for $CO_2$ transport. In the 2021 Re-stream study[117] investigated the possibility of reusing existing oil and gas infrastructure in Europe for $CO_2$ transport. As shown in Figure 21, the study concluded that majority of the pipelines in Norway can be retrofitted for $CO_2$.

117 Carbon Limits and DNV. (2021). *Re-Stream: Study on the reuse of oil and gas infrastructure for hydrogen and CCS in Europe.* https://uploads-ssl.webflow.com/63e3b74820155d49e193aa74/647b4d4a9c693564252a112d_Re-stream-Report.pdf

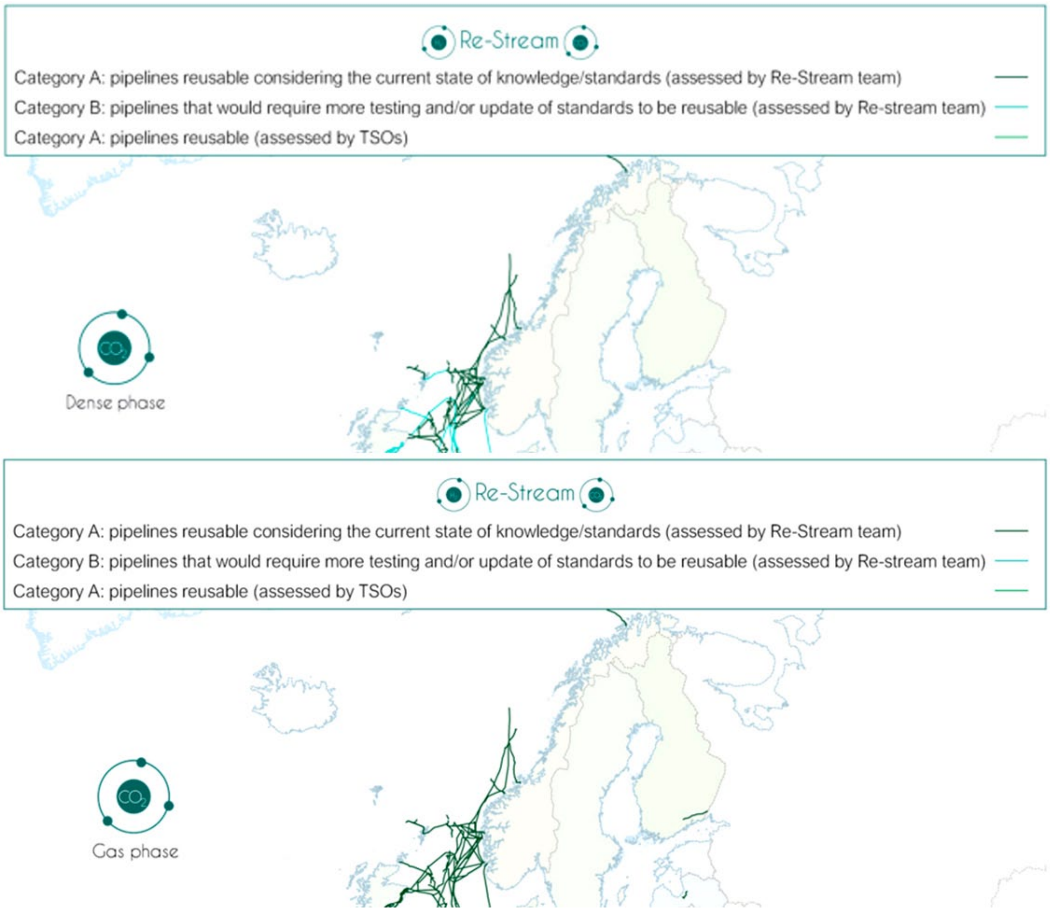



**Figure 21: Reuse of oil and gas pipelines for $CO_2$ transport in the dense phase and gas phase[118]**

Norway has significant potential for $CO_2$ transport development. The country emphasizes the development of CCS hubs which serve as pivotal collection and distribution points, strategically connecting diverse transportation modes and accommodating increased capacity and new sources of $CO_2$ emissions. Furthermore, existing transportation networks in Norway offer valuable opportunities for repurposing and optimization of $CO_2$ transport.

## 2.8. $CO_2$ storage in timber

Another $CO_2$ storage option is storage in timber. Besides forming a natural ecosystem, forests are an important carbon sink by filtering $CO_2$ out of the air and absorbing this in the biomass of the tree as biogenic carbon. The sustainable use of wood in durable products reduces the rise in $CO_2$ levels in the atmosphere.

Norway has vast forests, and timber is the most important raw material for its forestry-based industries. Around half of the timber felled is used by the timber industry, which manufactures wood products for housebuilding, glued-wood structures, doors, window-frames and furniture.

118 Carbon Limits, Re-stream study, 2022
119 Regjeringen. (2001). *Business and industry in Norway – the timber and pulp and paper industry.*
www.regjeringen.no/en/dokumenter/Business-and-industry-in-Norway---The-timber-and-pulp-and-paper-i8787ndustry/id419353/

Demand for timber in the construction industry in Norway is expected to continue evolving in response to several key trends and factors:

- Sustainability will greatly influence demand for timber. As countries and industries are trying to reduce carbon emissions and adopt more sustainable building practices, timber's role as a renewable and carbon-sequestering material is likely to expand.
- Timber's ability to sequester carbon makes it an attractive choice for carbon-neutral construction. As carbon reduction goals become more ambitious, timber will be increasingly favoured in construction projects aiming for net-zero emissions.
- Continued advancements in timber engineering and the development of engineered wood products are expanding the possibilities for timber in construction.
- Timber's natural insulation properties will continue to make it a preferred choice for energy-efficient buildings.

Figure 22 illustrates how removals of roundwood increased in the past 20 years. Significant growth has happened over the past ten years. As a result of the trends mentioned earlier, the demand for construction timber is expected to rise in the coming years.

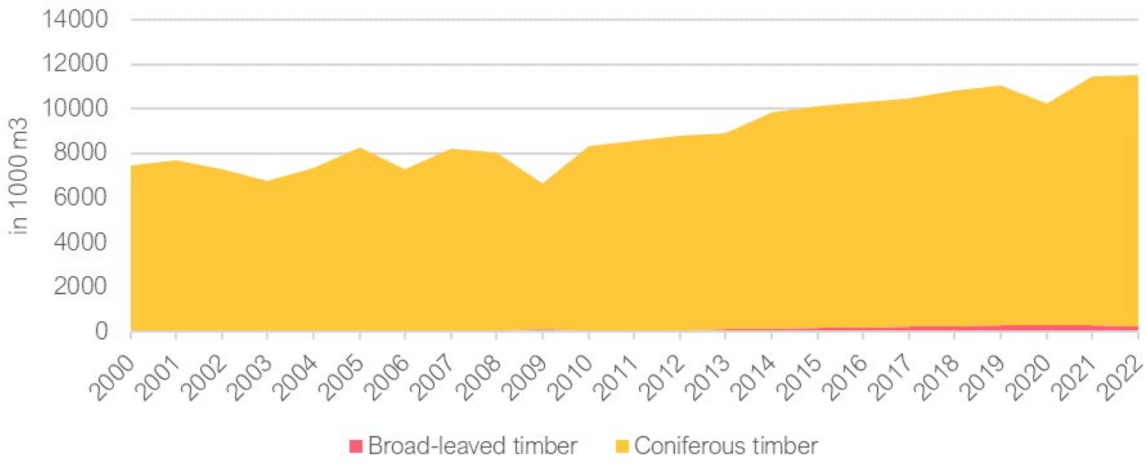



**Figure 22: Commercial roundwood removals (in 1,000 m³), by wood group[120]**

In 2022, the production of timber amounted to 11.5 mcm, with the majority originating from coniferous trees, equivalent to approximately 6.6 Mt of timber. Notably, the Norwegian government has not released any publicly available forecasts concerning the coming years of timber production in. Due to the absence of official projections and the limitations of the current data, making reliable estimates for timber production in 2050 is challenging.

## 2.9. Land restrictions in Norway

Restricted areas on the Norwegian mainland can generally be split into three categories: natural areas, built-up land, and cultural landscapes. Natural areas include environmentally important areas such as national parks, nature reserves, "Ramsar" sites (wetland sites designated to be of international importance under the Ramsar Convention), and other protected areas on land or in the territorial waters of Norway. The size of these protected natural areas within Norway's mainland is summarized in Figure 23, with national parks and landscape protected areas occupying the largest share.[121,122] Figure 24 depicts coverage of national parks (green shading), nature reserves (red shading), and Ramsar sites (blue shading) on the Norwegian mainland. In Svalbard and Jan Mayen, natural areas cover most of the land surface and territorial waters: 68.2% of Svalbard's land area and 87.7% of its waters are protected. These percentages are even higher in Jan Mayen: 99.5% of the land and 100% of the waters are protected.[123] As mentioned in Section 3.2, certain water bodies have additional environmental protections beyond basic water body protection and restoration standards. A map depicting these protected areas is presented in Figure 24.

120 Statistisk Sentralbyrå. (2022). *Commercial roundwood removals.* www.ssb.no/en/statbank/table/08979/tableViewLayout1/
121 Statistisk sentralbyrå (Statistics Norway). (2023). *Protected areas.* www.ssb.no/en/natur-og-miljo/areal/statistikk/vernede-omrader
122 Convention on Wetlands Secretariat. (2023). *Norway.* www.ramsar.org/country-profile/norway
123 Miljødirektoratet. (2023). *Vernet Natur.* https://miljostatus.miljodirektoratet.no/tema/naturomrader-pa-land/vernet-natur/

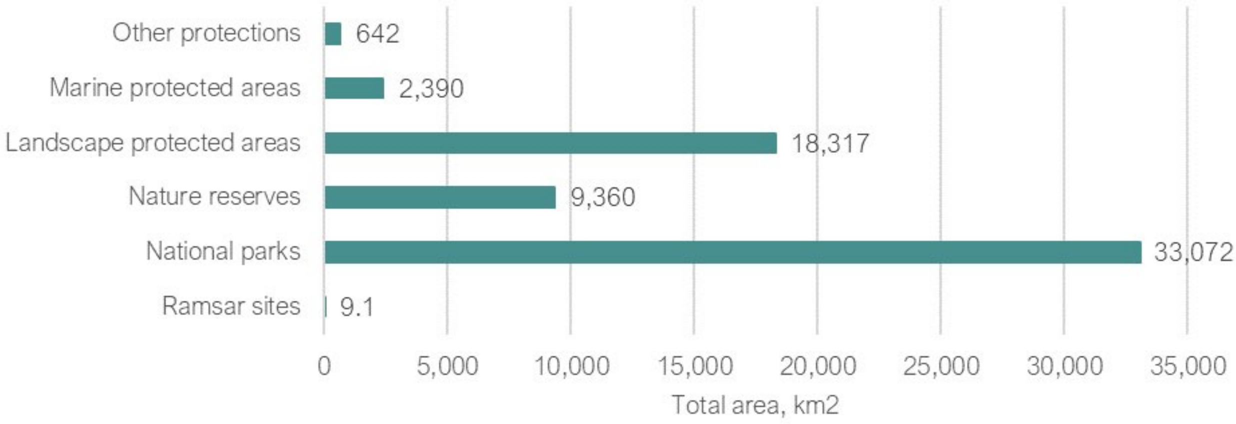



**Figure 23: Protected areas in mainland Norway[124]**

Some landscapes belong to more than one category, so the total protected natural area is less than the sum of the values provided in the chart: approximately 17.6% (57,000 km$^2$) of the country's mainland, and 4.5% of its marine areas are protected natural areas. Most of the protected natural areas in Norway are mountainous, and mountains also represent the most protected environment.

Built-up areas in Norway also pose land use restrictions. Only 1.8% (5,694 km$^2$) of Norway is considered built-up, and most of these areas are residential or used for technical infrastructure. The Cultural Heritage Act was written into Norwegian law in 1978. The act was intended to preserve and protect important archaeological, architectural, and cultural areas.[125] These areas also include a "security" zone around their outermost extents, to provide an additional protective buffer.

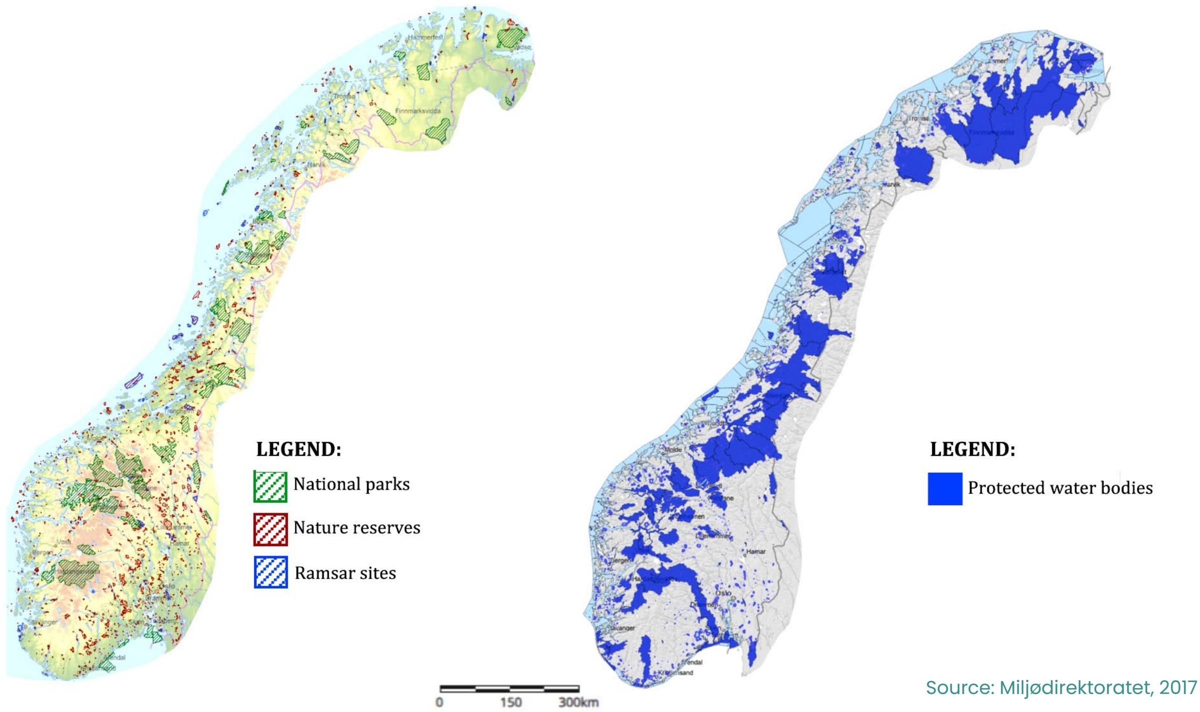



**Figure 24: (Left) National parks (green shading), nature reserves (red shading), and Ramsar sites (blue shading) on the Norwegian mainland. (Right) Protected water bodies in Norway**

124 Carbon Limits assessment using information from Statistisk sentralbyrå; and Convention on Wetlands Secretariat
125 Klima- og miljødepartementet (Ministry of Climate and Environment). (1978). *Cultural Heritage Act.* www.regjeringen.no/en/dokumenter/cultural-heritage-act/id173106/

The extent of officially designated protected natural area in Norway has not increased significantly since 2011, and is not expected to do so in the future: the Norwegian Ministry of Climate and Environment indicated in a 2015 report that mainly forest and marine areas would be the focus for limited additional protection.[126,127] The government intends to protect 30% of marine areas and double the percentage of protected forested areas to 10%.260 However, the latter goal is harder to reach due to diverse, small-scale ownership of forested land (88% of forested land is privately owned). Despite limited plans for expanding officially designated protected areas, the extent of built-up land is likely to increase with urbanization and population growth.

In the analysis for available land resources, all water bodies, wetlands, built environment, proposed protected areas, forests and arable land (pastures and grazing land) were removed from potential land area list. Despite removing this significant land area, over 121,731 km$^2$ could be available for new CDR pathways deployment.

Having presented the physical geography aspects of Norway, the next section presents the policy analysis for Norway, that could affect the deployment of CDR in the country. After presenting the physical and political overview, the theoretical potential for different CDR pathways in Norway is presented.

© Echo - Unsplash

126 Miljødirektoratet. (2022). *Naturområder på land.* https://miljostatus.miljodirektoratet.no/tema/naturomrader-pa-land/
127 Klima- og miljødepartementet (Ministry of Climate and Environment). (2015). *Naturexfor life: Norway's national biodiversity action plan.* www.regjeringen.no/contentassets/902deab2906342dd823906d06ed05db2/en-gb/pdfs/stm201520160014000engpdfs.pdf

# 3. Existing policy

Policy instruments, either already implemented or planned for future implementation, can facilitate but also hinder an effective scale up of CDR. Such instruments can be identified at nearly all governance levels, ranging from the national-domestic, to the supranational-European and the international level. The following sections provide a high-level overview of these policy instruments, and an initial assessment how they might impact a dedicated CDR rollout in Norway.

## 3.1. CDR within Norway's climate strategy

According to the Climate Change Act,[128] Norway aims to become a low-emission society by 2050. This goal involves reducing greenhouse gas (GHG) emissions by 90-95% compared to 1990. Norway, however, has not committed to a clear net-zero target or net-negative target in its domestic policy framework. Neither has the country specified whether any of the climate goals would be achieved by carbon removals. Furthermore, it should be noted that part of Norway's carbon management strategy focuses on CCS as a pivotal mitigation technology to realise emission reductions, but not CDR per se.

Figure 25 depicts historical emissions in Norway, as well as future emissions reduction targets and emissions projections based on existing climate policies. The chart illustrates a rise in emissions between 1990 and 1996 to approximately 55 $MtCO_2eq$, where they remained relatively steady for the next two decades. On the secondary axis, the chart highlights how public climate-related expenditure has nearly doubled from 4.1 billion NOK in 2013 to 8 billion NOK in 2021. During that period, Norway's emissions fell from 54 $MtCO_2eq$ to 49 $MtCO_2eq$, with the latter representing an approximate 5% reduction in emissions compared to 1990 levels. Current projections estimate that under existing national climate policy, Norway will achieve only a 20% reduction in emissions by 2030, in contrast to the national target of 55%.


[1] $CO_2$ equivalents according to AR5, the IPCCs Fifth Assessment Report. Does not include emissions from ocean transport and international air transport or LULUCF. Source: SSB (**www.ssb.no/en/statbank/table/13931**).

[2] 2030 emissions projected based on existing Norwegian climate policies submitted to the European Environment Agency in 2021. Source: Climate Action Tracker (**https://climateactiontracker.org/countries/norway/targets**).

[3] Includes expenditures for the protection of air and climate in public administration under the: purchase of goods and services, salary costs, capital wear and tear, environmental protection investments, transfers abroad, other transfers, and subsidies. Source: SSB (**www.ssb.no/en/statbank/table/12456/tableViewLayout1**)

**Figure 25: Historical emissions in Norway, emissions reduction target and emissions projections based on existing climate policies**

128 Norwegian Ministry of Climate and Environment. (2018). *Act relating to Norway's climate targets (Climate Change Act).* https://lovdata.no/dokument/NLE/lov/2017-06-16-60

In June 2023, the Norwegian Environment Agency released the analysis of the mitigation potential of 85 various measures.[129] The report notes that some measures (i.e., changing public eating and food waste habits or phasing out diesel/petrol vehicles) will take time to fully implement. It may not be possible to achieve significant impact with long-term approaches such as these in the next six years. Meanwhile, the report states that electrification and CCS have the greatest potential for reducing emissions in the country and notes the need for related infrastructure such as power grids and charging infrastructure or $CO_2$ transport and storage infrastructure. In order to minimize the time required to realize the impacts of climate-related expenditures, Norway can attempt to reduce implementation time by improving the efficiency of the licensing process for new power projects. CCS project licensing can likely benefit from similar facilitation practices.

In October 2023, the Norwegian Government published the climate status and plan[130] outlining strengthened measures that would help the country reach its 2030 emissions reduction target. According to the climate plan, the new measures in the non-ETS sector in Norway will allow the country to stay within its emissions budget for the period 2026 – 2030. At the same time, the plan highlights that there is a considerable uncertainty when it comes to future emissions projections and the effect of climate policy.[131]

Norway's climate policy involves cross-sectoral coordination among government agencies, ministries, and local governments. Table 10 presents an overview of different institutions and their responsibilities within Norwegian climate policy.

| Institution | Responsibilities |
|---|---|
| **Stortinget** | • Decides the overall national climate policy |
| **The Norwegian Government** | • Administration and implementation of direct regulations and economic mechanisms |
| **The Ministry of Climate and Environment** | • Coordination and implementation of the climate policy in Norway, cross-sectoral responsibility<br>• Operation of Norwegian carbon credit procurement program |
| **The Ministry of Finance** | • Responsible for various tax schemes |
| **Other ministries** | • Administration and implementation of policies in their respective sectors |
| **Local governments** | • Implementation of policies and measures at the local level (e.g., waste management) |
| **The Norwegian Water Resources and Energy Directorate (NVE) (a directorate under the Ministry of Petroleum and Energy)** | • Responsible for an integrated and environmentally sound management of the country's water resources<br>• Promotion of efficient energy markets and cost-effective energy systems and energy use |

**Table 10: Norwegian institutions and their responsibilities withing Norwegian climate policy**

**Box 1: Cross-sectoral coordination in Norway's climate policy**

129 Miljødirektoratet. (2023). *Klimatiltak i Norge mot 2030: Oppdatert kunnskapsgrunnlag om utslippsreduksjonspotensial, barrierer og mulige virkemidler – 2023.* www.miljodirektoratet.no/publikasjoner/2023/juni-2023/klimatiltak-i-norge-mot-2030/
130 Regjeringen. (2023). *Statsbudsjettet 2024: Norge skal nå klimamålene.* www.regjeringen.no/no/aktuelt/norge-skal-na-klimamalene/id2996215/
131 Regjeringen. (2023). *Regjeringas klimastatus og -plan.* www.regjeringen.no/no/dokumenter/regjeringas-klimastatus-og-plan/id2997247/?ch=1

The following sub-sections provide an overview of the existing and planned policies and regulatory mechanisms in Norway relevant for different groups of CDR technologies.

## 3.2. Cross-sectoral policies, incentives and support mechanisms

Norwegian climate policy relies primarily on $CO_2$ taxes and emissions trading.[132] Setting a price on GHG emissions may not only incentivize action to reduce emissions, but also encourage investments in research and development to facilitate future emissions reduction strategies. In this sense, even though GHG taxes do not apply to biogenic $CO_2$, they can drive the necessary investments in development and promotion of technologies and projects relevant for various CDR pathways. For example, Norway places a $CO_2$ tax on mineral oil, petrol, and emissions from petroleum extraction on the continental shelf, on natural gas and liquefied petroleum gas (LPG), while offering an exemption to facilities deploying CCS. This have already incentivized CCS projects like Sleipner and Snøhvit, and may incentivize further investments in CCS technologies – as obligated facilities receive a refund of the $CO_2$ tax paid on their fossil products, equivalent to the amount of $CO_2$ captured and stored.[133] This might have a spill-over effect on the CDR pathways related to CCS (Bio-CCS and DACCS) in form of further development and reduced costs associated with $CO_2$ capture and storage technologies; establishment of CCS hubs; and further development of $CO_2$ storage sites.

Another example is the Norwegian waste incineration tax, which applies to the fossil part of $CO_2$ emitted by incineration plants. The $CO_2$ that is captured and stored is exempt from the tax[134], which may have a positive spill-over effect on carbon removals, since part of the $CO_2$ emitted from incineration plants in Norway comes from biogenic sources.

### R&D and Innovation

Full-scale projects have the option to seek support from Enova, a state-owned enterprise under the Ministry of Climate and Environment, providing financial support and guidance for climate and energy projects to stakeholders including businesses, households, and local governments. Funding for these projects is sourced from the Climate and Energy Fund.[135] However, this funding mechanism primarily focuses on late-phase technology development and early-stage demonstration, potentially leaving commercially immature technologies with high costs without adequate support.

## 3.3. Regulatory framework and support mechanisms relevant to CCS related CDR pathways

As of today, there is no established regulatory framework for industrial carbon removals (e.g., DACCS or Bio-CCS) in Norway. There are however several regulatory and economic instruments in place that are aimed at facilitating development and deployment of CCS technologies, which will have an indirect effect on these CDR pathways.

As mentioned above, CCS plays a significant role in Norway's climate strategy. In the country's 8th National Communication, CCS is identified as one of the top five priority areas for advancing Norway's national climate efforts and the government's CCS strategy encompasses a range of activities, spanning from research, development, and demonstration projects to large-scale initiatives.

In 2019, Norway, together with the Netherlands, contributed to the implementation of changes to the London Protocol to permit cross-border transport of $CO_2$, thus eliminating one of the significant barriers for the development of CCS in Europe.[136] The Protocol aims at controlling marine pollution by waste dumping at sea, and as such, exporting $CO_2$, waste, or any other material to another country for permanent storage at sea. Though the Protocol was amended by contracting parties to allow for cross border transportation of $CO_2$ for sub-seabed storage, it has not yet been ratified by enough parties for the amendment to enter into force. In 2019, the contracting parties reached an agreement for the provisional application of this amendment, allowing countries to sign bilateral agreements. In April 2023, Norway and Belgium started negotiations to establish a bilateral agreement addressing the cross-border transport and storage of $CO_2$, under the framework of the London Protocol.[137]

132 Norwegian Ministry of Climate and Environment. (2023). *Norway's Eighth National Communication.* www.regjeringen.no/contentassets/a69c7662e3ed4b1fa2f946f8e966343a/en-gb/pdfs/t-1582-e-norways-eighth-national-communication.pdf
133 Skatteetaten. (n.d.). *Mineral product tax.* http://tiny.cc/p899yz
134 Skatteetaten. (n.d.). *Avgift på forbrenning av avfall.* www.skatteetaten.no/bedrift-og-organisasjon/avgifter/saravgifter/om/avfallsforbrenning
135 Enova. (n.d.). *Enova.* www.enova.no
136 IEA. (2020). *CCUS in Clean Energy Transitions. A new era for CCUS.* www.iea.org/reports/ccus-in-clean-energy-transitions/a-new-era-for-ccus
137 Regjeringen. (2023). *Belgium and Norway will work closer on cross-border transport and storage of $CO_2$* http://tiny.cc/ef99yz

Norway is home to the world's largest facility for testing, verification and demonstration of different industrial-scale $CO_2$ capture technologies. The Technology Centre Mongstad (TCM) was established in 2012, and is owned by the Norwegian Government, Equinor (formerly Statoil), Shell, and TotalEnergies.[138] TCM's experts command significant recognition within the international CCS community, and in total, approximately 6 billion NOK has been invested in construction and further development of the plant.

## Demonstration projects

A comprehensive CCS demonstration project named "Longship" is currently under development in Norway.[139] Longship comprises two Norwegian $CO_2$ capture facilities, one at a waste incineration plant (Hafslund Oslo Celsio[140]) and one at a cement plant (Norcem Brevik[141]), as well as a $CO_2$ transport and storage project known as "Northern Lights"[142] – a joint venture between Equinor, Shell, and TotalEnergies. The captured $CO_2$ will be stored at a storage site on the Norwegian continental shelf. The Longship CCS project has received 80% investment funding and 95% operational cost funding from the Norwegian government. The project is expected to start operation activities in 2024, capturing and storing 1.5 $MtCO_2$pa during the project's first phase and then planning to expand to capture and store up to 5 $MtCO_2$pa.

At the Norcem cement plant, the aim is to capture approximately 0.4 $MtCO_2$ pa. This would account for approximately half of the total $CO_2$ emissions produced by the facility, with about 10% of the captured $CO_2$ coming from biogenic sources. Hafslund Oslo Celsio aims to capture 90% of the emissions from the waste incineration facility, which would also amount to roughly 0.4 $MtCO_2$pa. Approximately 50% of these emissions will be bio-$CO_2$.[143] Furthermore, new exploration permits for $CO_2$ storage acreage have been offered (see Figure 18 and Table 8).

## R&D and Innovation

In Norway, R&D activities in the field of CCS can receive funding through existing national frameworks for research and innovation. Projects can seek support from programs like the CLIMIT program[144] and the Research Council of Norway.[145] The CLIMIT program is a national initiative focused on research, development, and demonstration of technologies related to the CCS, providing support to a wide range of projects across various stages of the CCS development chain. In addition to the CLIMIT program, Norway has established several research centres such as the Norwegian CCS Research Centre (NCCS) covering various aspects of CCS technology, including capture methods, transportation, and geological storage of $CO_2$. These centres operate with co-financing from multiple sources, including the Research Council of Norway, industry partners, and research collaborators.

## On the horizon

Considering the substantial uncertainty in the cost estimates for CCS-based CDR projects and the varying levels of risk acceptance among stakeholders, Norway acknowledges the importance of ensuring predictability in funding mechanisms for businesses. To address this, Norway is currently exploring two potential approaches for supporting Bio-CCS and DACCS: a reverse tax and a reverse auction.[146]

The reverse tax mechanism is a rights-based system where entities are financially rewarded for each ton of $CO_2$ they remove over a specified period. In this context, the state could implement a negative tax, directly linked to the $CO_2$ tax, essentially refunding 2000 NOK per $tCO_2$ removed (using 2020 currency values) for a duration of ten years. To ensure DACCS projects are adequately supported, considering a higher support level for this more costly family of technologies, as the USA has done, it has been suggested to combine this support with funding from sources like the Innovation Fund or Enova, as well as the sale of removal credits on the Voluntary Carbon Market (VCM). Furthermore, it is proposed that the reverse tax system can be offset against future incentives at the EU level, potentially through the EU Emissions Trading System (ETS), allowing for coordination with broader European efforts.

138 Technology Centre Mongstad. (n.d.). *Technology Centre Mongstad.* https://tcmda.com
139 Gassnova. (2023). *The Longship CCS Project.* https://ccsnorway.com/the-project
140 Hafslund Oslo Celsio. (n.d.). *Hafslund Oslo Celsio.* https://celsio.no
141 Heidelberg Materials. (n.d.). *Brevik cement plant.* /www.sement.heidelbergmaterials.no/en/NorcemBrevik_eng
142 Northern Lights. (n.d.). *Northern Lights.* https://norlights.com
143 NTB. (2020). *$CO_2$-rensing: EU setter foten ned for bokføringsknep.* www.finansavisen.no/nyheter/politikk/2020/09/14/7566624/co2-rensing-eu-setter-foten-ned-for-bokforingsknep
144 Gassnova. (2023). CLIMIT. https://climit.no/en
145 Forskningsrådet. (2023). *The Research Council of Norway.* www.forskningsradet.no/en
146 Miljødirektoratet. (2023). *Industrien kan fjerne $CO_2$ med nye virkemidler.* www.miljodirektoratet.no/aktuelt/fagmeldinger/2023/mars-2023/industrien-kan-fjerne-co2-med-virkemidler

On the other hand, a reverse auction is a process where potential project developers bid on support funding to execute CCS and CDR projects. The goal is to select projects that can deliver the maximum carbon capture or removal per unit of funding, ensuring cost-effectiveness within a specified budget, as well as providing predictability in terms of the number of tonnes of CDR achieved. There are however some drawbacks of this mechanism that need to be addressed. For example, the competitive nature of auctions can create a sense of urgency among project developers to submit their bids, potentially causing difficulties for projects that require a more gradual scaling process. In addition, relying solely on price as the criterion in a single auction may disadvantage DACCS projects, potentially limiting their participation. Similar to the reverse tax mechanism, the reverse auction mechanism can be offset against future EU incentives.

## 3.4. Regulatory framework and support mechanisms relevant to other CDR pathways

### Agriculture

In 2019, the agricultural organisations in Norway (the Norwegian Farmers' Union and the Norwegian Smallholders' Union) entered into a voluntary agreement with the government, where the parties committed to combine efforts in reducing GHG emissions by 5 $MtCO_2$ in the period 2021-2030 and enhancing CDR within the agricultural sector.[147] One of the policies that aims to bolster carbon removals is a national target to restrict the conversion of agricultural land to other purposes. The current target is 300 ha/year, which corresponds to approximately 0.03% of the total utilized agricultural area. While this target has already been achieved in 2021, more ambitious objectives and strategies are currently under consideration.

Furthermore, in order to support the country in achieving its climate goals by 2030 and its objective of becoming a low-emission society by 2050, a new funding mechanism known as "Bionova" was established by the Norwegian government.[148] Bionova's primary focus is reduction of greenhouse gas emissions, fostering innovation and value creation within the bioeconomy, particularly in connection with agriculture, forestry, and aquaculture. This also includes promotion of increased removals and carbon sinks at the farm level.

In Norway, each farmer who performs various environmental and climate change mitigation measures at a farm level, can apply for financial support through the regional agri-environmental programs (RMP),[149] a support mechanism aiming to address environmental issues in various geographical regions of the country. Historically, the main focus of the RMP has been promoting agricultural practices that reduce environmental challenges such as erosion, run-off, and preserving cultural landscapes, among others. During the recent years, however, the programs have been extended to include support for several climate-related measures. For example, from 2022, the support is offered to farmers who use on-farm climate advisors to collaborate on development of an action plan including a list of potential measures to reduce the carbon footprint of the farm.[150] Moreover, from 2023, measures aiming at promoting soil health and soil carbon sequestration are included separately as one of the focus areas within the RMP. Such measures include for example spreading of biochar and planting of catch crops.[151]

Historically, there has been extensive land conversion from peatland to cropland in Norway. In 2021, the restrictions on the cultivation of peatland were enforced, as peatlands serve as storage for organic material, particularly carbon. The prohibition on cultivating new peatlands was primarily driven by climate considerations.

### Forestry

The primary legislation governing land use management in areas outside of protected zones is provided in the Planning and Building Act, which covers approximately 83% of the nation's land.[152] According to the Act, while the responsibility for spatial planning lies within municipalities, the central government provides regulations and planning guidelines. These guidelines for municipalities include, among others, the requirement to adopt "measures and policies to reduce deforestation and to increase carbon sinks in forests and other land".

147 Norges Bondelag. (2019). *Inngår klimaavtale for jordbruket.* www.bondelaget.no/bondelaget-mener/miljo-og-klima/klima/inngar-klimaavtale-for-jordbruket
148 Innovasjon Norge. (2023). *Bionova - tilskudd til bioøkonomi og klimatiltak.* www.innovasjonnorge.no/tjeneste/bionova-tilskudd-til-biookonomi-og-klimatiltak
149 Landbruksdirektoratet. (2023). *Regionalt miljøtilskudd i jordbruket (RMP).* www.landbruksdirektoratet.no/nb/jordbruk/ordninger-for-jordbruk/regionalt-miljotilskudd-rmb
150 Klimasmart Landbruk. (2023). *Klimarådgivere i hvert fylke (fylkesinndeling fra 01.01.24).* https://klimasmartlandbruk.no/finn-klimaradgivere/category882.html
151 Landbruksdirektoratet. (2023). *Jord og jordhelse.* www.landbruksdirektoratet.no/nb/jordbruk/miljo-og-klima/jord-og-jordhelse
152 Miljødirektoratet, Landbruksdirektoratet, Norges vassdrags- og energidirektorat og Statens vegvesen. (2023). *Tiltaksanalyse for skog- og arealbrukssektoren (LULUCF): Hvordan Norge kan redusere utslipp av klimagasser fra arealbruksendringer innen 2030.* www.miljodirektoratet.no/publikasjoner/2023/april-2023/tiltaksanalyse-for-skog-og-arealbrukssektoren

Forest policies in Norway include a broad range of measures, encompassing legislative frameworks, taxation policies, economic support systems, and research initiatives. The Forestry Act,[153] which came into effect in 2006, serves as a cornerstone of these measures. The primary objectives of this legislation include fostering the sustainable management of forest resources to drive local and national economic growth, while simultaneously ensuring the preservation of biological diversity, landscape integrity and opportunities for outdoor recreation. At the same time, the Forestry Act also contributes to promoting $CO_2$ sequestration by, for example, requiring that forest owners regenerate their areas within three years following harvesting operations.

Furthermore, Norway offers a variety of financial support mechanisms (subsidies) for such measures as genetic improvement and plant breeding (to increase the survival rate of forests and increase the growth of trees) and fertilization of forest.

### On the horizon

In October 2022 the government presented a new climate plan, introducing a number of measures and policies which are currently under discussion and evaluation. Implementation of measures that enhance carbon removals in the forest sector was identified as one of the important objectives, especially if such measures and policies have the potential to significantly increase carbon removals and are relatively easy to implement. For example, it was proposed that the Forestry Act is updated with new requirements setting a threshold age for logging of trees.

In addition, a new support mechanism providing subsidies for afforestation of new areas is currently under consideration in Norway. The Norwegian Environment Agency and the Norwegian Agriculture Agency are working on a proposal for a subsidy scheme to support this measure, along with accompanying guidelines.

## 3.5. International policies and support mechanisms relevant for Norway

Linked to the mitigation policy taxonomy proposed by the IPCC,[154] policy instruments can be broadly grouped into different categories and designed in various ways – from a more hierarchical, top-down governance to bottom-up action. The policy instruments that are most relevant for Norway are described in more detail in the following section. More background on each type of instrument can be found in Annex 5.

### Public mitigation targets

National mitigation targets are encompassed by nationally determined contributions (NDCs) and long-term low greenhouse gas emission development strategy (LT-LEDS).

Norway's updated nationally determined contribution (NDC), which was submitted to the UNFCCC in 2022 (and which is going to be implemented jointly with Iceland and the European Union), represents progress compared to its first submission by aiming for a more ambitious emission reduction target. Norway plans to reduce emissions by at least 55% by 2030 below 1990 levels. It is worth mentioning that the updated target is not yet integrated into the Norwegian Climate Change Act, which provides the legal framework for Norwegian climate policy and reinforces the country's commitment under the Paris Agreement.

With regards to the roles of removals or sinks, the Norwegian NDC only notes forest sinks, which have been increased over the past decade. According to Norway's domestic forestry plan, the average removal volume from forests can amount to up to 24 $MtCO_2e$ pa (approximately 50% of Norway's $CO_2e$ emissions from economic activity in 2021[155]) between 2021-2025.[156]

Norway's long-term low greenhouse gas emission development strategy (LT-LEDS) for 2050, which was also submitted to the UNFCCC, points into a similar direction.[157] Although the strategy does mention CDR, it mainly refers to CDR's role in reaching net-zero at a global level as highlighted in the IPCC reports and their emission trajectories. The strategy only refers to concrete Norwegian removal activities with regards to their forest sinks, but apart from that remains rather vague and stresses the priority of emission reduction efforts instead.

153 Regjeringen. (2005). *Act relating to forestry (Forestry Act)*. https://tinyurl.com/4fjwheeu
154 Intergovernmental Panel on Climate Change (IPCC). (2007). *IPCC Fourth Assessment Report: Climate Change 2007: Working Group III: Mitigation of Climate Change*. https://archive.ipcc.ch/publications_and_data/ar4/wg3/en/ch13.html
155 SSB. (2022), *Emissions from Norwegian economic activity*. www.ssb.no/en/natur-og-miljo/miljoregnskap/statistikk/utslipp-fra-norsk-okonomisk-aktivitet
156 Climate Action Tracker. (2022). *Norway*. https://climateactiontracker.org/countries/norway/2022-06-29/policies-action
157 Norway. (2020). *Norway's long-term low-emission strategy for 2050*. https://unfccc.int/documents/266947

### Regulatory mandates

Regulatory mandates can take various forms, ranging from emissions standards (e.g., for a specific maximum greenhouse gas emissions intensity in energy or industry) to sector agreements, including dedicated targets for mitigation volume or number of installations/plants.

Although Norway is not a European Union member state, it is a party to the European Economic Area (EEA) and is linked to various EU policies and frameworks. In 2019, Norway entered into a climate agreement with the EU, setting the stage for collaborative efforts to reduce emissions by a minimum of 40% by 2030 compared to 1990 levels. This collaboration involves Norway's active participation in the EU's climate framework, including participation in the EU Emissions Trading System (ETS), which the country had been part of before. In addition, the new agreement also encompasses two other key components: the Effort Sharing Regulation (ESR) and the Land Use, Land Use Change, and Forestry (LULUCF) Regulation. The latter establishes Norway's commitment to achieve net-zero emissions from the LULUCF sector over the period 2021 – 2030, meaning that the total emissions from this sector should not surpass the amount of carbon sequestered. The scope of this commitment extends to various components of land use and forestry practices, including deforested areas, afforested areas, managed forests, cultivated land, pastureland, as well as carbon storage in wood products. Additionally, from 2026 onward, water and wetlands will also be incorporated into this commitment.

### Activity-oriented subsidies for research, design, development and demonstration (RDD&D)

Activity-oriented subsidies can accelerate the research, design, development and demonstration of removal methods, and are paramount to improve the technology readiness and eventually also bring down its associated costs.

Norway is associated with Horizon Europe, the EU's multi-billion research and innovation framework, and is eligible for receiving dedicated funding.[158] Under Horizon Europe's three funding pillars, various calls directly and indirectly target CDR and provide substantial trans- and interdisciplinary funding opportunities, amounting to around 2.6% of the total 2023-2024 Horizon budget.[159] While the direct funding for CDR focuses predominately on Bio-CCS, geological carbon storage and blue carbon projects, the indirect funding available under Horizon can also play an important role for CDR activities, namely support for generic CCS projects. This may include joint storage sites and (transboundary) carbon infrastructure projects, as well as developments of monitoring, reporting and verification methodologies to adequately keep track of amounts of carbon emissions reduced or removed by mitigation activities.

To support the scaled implementation of a European-wide $CO_2$ infrastructure, the EU Connecting Europe Facility is yet another vehicle that has already provided funding to several cross-border $CO_2$ networks, hubs and clusters in the UK and Norway.

One of the EU's Innovation Fund's overall aims is to provide financing for piloting climate protection projects.[160] With an endowment of around EUR 40 billion until 2030, substantial sums are available for CCS and removal projects.[161] However, the Innovation Fund focuses more on time-limited one-time support for first-of-its kind projects, hence long-term sustainable financing is not envisaged.

### Carbon pricing instruments

Carbon pricing instruments can serve as yet another funding avenue for accelerating the CDR scale up in an efficient manner, by putting a concrete price on carbon.

Almost 50% of emissions in Norway are covered by the EU ETS. Under the EU ETS, companies engaging in CCS activities are exempted from the requirement to purchase emission allowances for the corresponding amount of $CO_2$ that they have captured and stored. This provision serves as an incentive for companies to invest in CCS technologies and encourages the reduction of $CO_2$ emissions through capture and storage to avoid the cost of emission allowances.[162]

158 Directorate-General for Research and Innovation. (2021). *Iceland and Norway are the first countries associated to Horizon Europe.* **http://tiny.cc/x9e9yz**
159 Carbon Gap. (n.d.). *Horizon Europe.* **https://tracker.carbongap.org/policy/horizon-europe/**
160 Directorate-General for Climate Action. (n.d.). *Innovation Fund.* **https://climate.ec.europa.eu/eu-action/funding-climate-action/innovation-fund_en**
161 European Commission. (2023). *EU Innovation Fund and Certification of Carbon Removals.* **www.cewep.eu/wp-content/uploads/2023/06/2.3-Christian-Holzleitner.pdf**
162 European Commission. (n.d.). *Carbon capture, use and storage.* **http://tiny.cc/ebe9yz**

To achieve its target of a 55% reduction in emissions by 2030, Norway has indicated that, if necessary, it will use voluntary cooperation under Article 6 of the Paris Agreement to fulfil the part that goes beyond what is achieved through the climate cooperation with the EU.[163] This formulation indicates that Norway can be expected to be a buyer rather than a seller of carbon credits, potentially including removal credits.

## On the horizon

There are two major initiatives on the political horizon that will potentially become relevant for Norway's CDR developments. Namely, these are (1) reforms of the EU ETS to include the waste sector and removals and (2) the EU's Carbon Removal Certification Framework (CRCF).

### a) Reforms of the EU ETS

The EU describes the ETS as the "main incentive" for CCS deployment.[164] Yet the current provisions and price levels of the EU ETS do not provide adequate incentives for affected companies to engage in CCUS and CDR activities. Several challenges and shortfalls can be identified with regards to the current design of the ETS, considering it should become a meaningful vehicle for a wider and faster CCUS and CDR rollout. Currently, a reform of the EU ETS[165] is on its way, with some of the alterations addressing such shortfalls. Other, more substantial reforms are under discussion.

Historically, under the EU ETS Directive, the transportation of $CO_2$ through new pipelines was the only CCS component considered eligible for exemption from the obligation to purchase allowances. However, the reform within the EU ETS aims to broaden eligibility to include other modes of transport (e.g., by ship, rail or truck). The inclusion of these modes of $CO_2$ transport is expected to unlock opportunities for CCS activities among currently covered entities. This could become especially important for Norway, which is leading in European $CO_2$ storage capacities and is therefore in a good position to benefit from increased CCS activities (and potentially CDR methods relying on geological storage) fostered by the ETS reform. In addition, Norway could utilize its oil and gas-related infrastructure to enable $CO_2$ transport for storage in durable and long-term storage of $CO_2$ in products (e.g., building materials), which is also envisaged in the latest proposal for the ETS reform.

However, to provide further incentivisation for carbon capture,[166] it is advisable to extend the sectoral scope within the ETS itself. By 2026, the EU aims to integrate the fossil emission share of waste incineration plants into the EU ETS (emission reduction). In addition, biogenic emissions from waste incineration plants and from other biomass-treating facilities, as well as DAC facilities, might eventually be integrated into the EU ETS (carbon dioxide removal) – though this would require further regulatory changes. Such a move could, for example, allow the relevant entities to receive free allowances in the future, which could subsequently be sold to other actors within the system. If the scope of the ETS was expanded to include the waste sector, then the capture and storage of both biogenic and fossil $CO_2$ from waste incineration would be incentivized through the establishment of a compliance-driven demand signal and predictable revenue stream. In such a case, the EU would need to make sure that the ETS incentive for Bio-CCS is in line with the Effort Sharing Regulation (ESR) in a way that biomass emissions are not double counted. Since the demand for biomass is likely going to increase in the future, it is essential to employ taxonomies and robust criteria to differentiate sustainable from non-sustainable biomass and biogenic waste, which will ultimately clearly distinguish between removals and reduction results (given these can both be realised with Bio-CCS).

With the expansion of coverage to new sectors and inclusion of biomass-processing installations, the ETS policy instrument has significant potential for creating a long-term incentive for CCS and CDR activities. Such a demand-driven incentivisation is key and would complement the many supply-push focused and often subsidy-driven (short-term) policy instruments that are currently being considered.

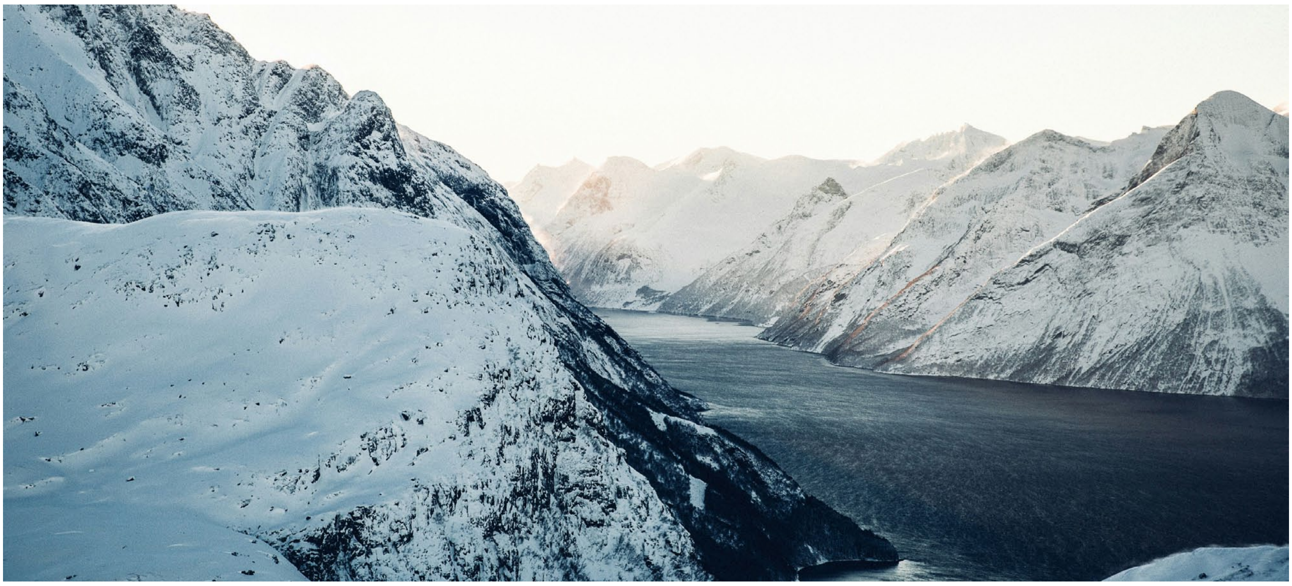
163 Norway. (2022). *Nationally Determined Contribution (NDC) of Norway for the timeframe 2021-2030.* **https://unfccc.int/sites/default/files/NDC/2022-11/NDC%20Norway_second%20update.pdf**
164 European Commission (2021). *Why do we need carbon capture, use and storage?* **http://tiny.cc/eof9yz**
165 See pdf for the proposed changes. **https://data.consilium.europa.eu/doc/document/ST-6210-2023-INIT/en/pdf**
166 Note that this includes capture from both emission reduction and emission removals.

**b) EU Carbon Removal Certification Framework (CRCF)**[167]

In 2022, the European Commission proposed a regulatory framework for voluntary carbon removal certification, which establishes quality criteria for removals, alongside rules for the certification process and the recognition of certification schemes in the EU. The Carbon Removal Certification Framework (CRCF) is intended to harmonise the often-diverging certification procedures and ensure that common quality criteria are upheld. In February 2024, a provisional political agreement was reached on the text of the CRCF. The agreement sets out “QU.A.L.ITY” criteria[168] for CDR activities – namely rules to ensure accurate quantification, genuine additionality, long-term storage, and sustainability of removals – with the criteria on long-term storage being the most salient for Norway as a source of storage potential. While the final text remains to be seen, the Regulation is expected to draw links to the upcoming Green Claims Directive as well as the Corporate Sustainability Reporting Directive (CSRD), which will drive demand by requiring CDR efforts claimed by corporates in the Union to be CRCF-certified. At the same time, the text is expected to restrict use of certified removals to contribute to the EU’s NDC only, and not contribute to third country NDCs or international compliance schemes. It is therefore unclear to what extent the CRCF will mobilise demand and revenue to stimulate CDR in EU Member States and third countries like Norway.

The CRCF will have further relevance for Norway as an EEA country, a country bordering the Union, and as a country with significant geological storage potential. The provisional agreement sets out the need to review the Regulation (after three years or by December 2028), considering the potential for permanent carbon storage in third countries. Introduction of $CO_2$ storage in third countries such as Norway (for CRCF-certified activities) would likely depend on such countries having regulatory requirements aligned with those of the EU, namely storage requirements aligned with the EU CCS Directive (which sets out rules for monitoring of, and liability for, stored $CO_2$). The EU Net Zero Industry Act, which also reached provisional agreement in February 2024, further enshrines an annual $CO_2$ storage target of 50 Mt and refers to geological storage sites “in the territory of the Union [or] its exclusive economic zones”.

Once the text is finalised, the European Commission will work with the CDR Expert Group to develop tailored certification methodologies for different CDR activities. There are therefore open questions about which activities will be prioritised for methodology development, and how more durable CDR methods like DACCS are approached relative to less durable methods with more co-benefits, such as land-based methods. Over the coming years, it will also become clearer how the EU will use the CRCF, and the certified CDR activities that result, to achieve its NDC and the targets set out in its Climate Law – with policies like the Industrial Carbon Management Strategy (ICMS) and the communication on 2040 climate targets contextualising the expected need for different forms of CDR. The ICMS identifies ‘clear opportunities to cooperate across borders’, noting Norway as the counterparty to the ‘first commercial cross-border agreement to capture $CO_2$ produced in the EU and ship it for storage’. Norway will undoubtedly be an important partner for delivering on EU climate ambitions as well as its own.



© Christiann Koepke – Unsplash

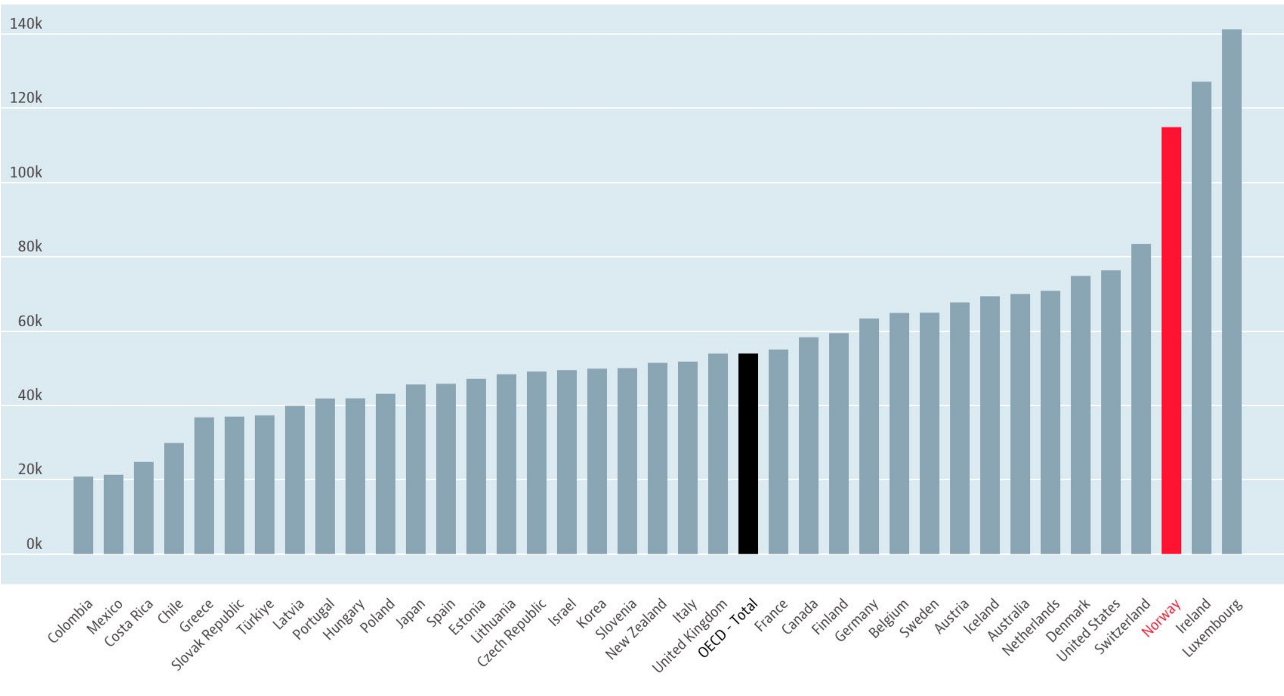
167 Proposal available at: http://tiny.cc/hdg9yz
168 Directorate-General for Climate Action. (n.d.). *Carbon Removal Certification.* http://tiny.cc/seg9yz

# 4. Norway's social geography

This section aims to provide an overview of the social geography of Norway, identifying the main enablers and blockers to the deployment of CDR. It is a combination of desk research and engagement exercises to capture the perceptions and aspirations of diverse actors. In addition to this social geography analysis, the NBT conducted a citizen engagement panel on assessing the impacts and options of CDR for Norwegian society. The results of this panel engagement are summarized in the Annex 5 of this report

## 4.1. Economy and climate

Norway has a highly developed mixed economy, with state ownership in strategic areas. The country has a very high standard of living compared with other European countries, and a robust welfare system. The Norwegian economy relies heavily on the oil and gas (O&G) sector as a source of finance for the welfare state, through direct ownership of oil fields, dividends from state interest in Equinor, licensure fees, and taxes. O&G exports account for 20% of the country´s total Gross Domestic Product (GDP) and contribute substantially to its GDP per capita, which is among the highest among the Organisation for Economic Co-operation and Development (OECD) countries. In Norway's 2023 draft budget, oil production was expected to rise by 15% from 2022 levels, while gas production growth was expected to remain very high following a 7.9% increase from 2021.[169] Revenues from the O&G industry were predicted to increase by 18% from 2022 to 2023.[170] This increase mainly results from the country becoming Europe's main O&G supplier following the EU-wide ban on Russian O&G imports in the wake of the Russia-Ukraine crisis. According to the Norwegian Petroleum Directorate (NPD), total petroleum output is expected to rise by 9% by 2024.[171]




Source: OECD (2023), Gross domestic product (GDP) (indicator). doi: 10.1787/dc2f7aec-en

**Figure 26: Gross domestic product (GDP) per capita among OECD countries. (US dollars/capita, 2022 or latest available)**

169 Det Kongelige Olje- og energidepartement. (2022). *Prop. 1S (2022 – 2023): Proposisjon til Stortinget (forslag til stortingsvedtak).* www.regjeringen.no/contentassets/eed690487f7846c397104ee2b984de1b/no/pdfs/prp202220230001oeddddpdfs.pdf
170 Solsvik, T. and Adomaitis, N. (2022). *Norway expects to earn record $131 bln from oil and gas in 2023.* www.reuters.com/business/energy/norway-hikes-tax-oil-industry-by-nok-2-bln-2023-2022-10-06
171 Adomaitis, N. (2022). *Norway oil and gas output to rise 9% by 2024, regulator says.* www.reuters.com/article/norway-oil/update-2-norway-oil-and-gas-output-to-rise-9-by-2024-regulator-says-idUSL8N2TT1Y1

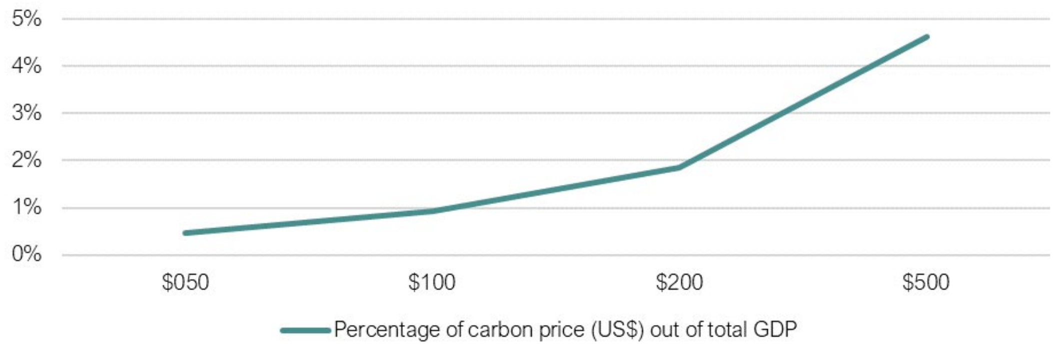
Despite the central role of fossil fuels in its economy, Norway has committed to reduce emissions by 55% by 2030, compared to 1990 levels. As of January 2021, the carbon tax rate stood at around 590 NOK (51 EUR / 54 USD) per tonne of $CO_2$ equivalent ($CO_2e$). The country announced that it will triple its tax rate to 2000 NOK (175 EUR /185 USD) per tonne of $CO_2e$ by 2030, indicating gradual increase from its current level over time. Norway also participates in the EU ETS, meaning that sectors including electricity and heat generation, energy-intensive industry, aviation, and maritime transport are subject to the target to reduce GHG emissions by 62% by 2030.[172] The OECD estimates that approximately 83% of GHGs in Norway are subject to a net effective carbon rate (a measure of carbon pricing levels that includes carbon taxes, emissions trading systems and fuel excise taxes).[173]

As part of its Climate Action Plan for the period 2021–2030, Norway plans to shift away from fossil fuels to renewable energy. Norway has built the world's largest floating offshore wind project – Hywind Tampen – which became operational in 2023 and generates an installed capacity of 88 megawatts. Norway plans to increase the efficiency of its current licensing process for offshore wind to meet its 2030 target.

The Climate Action Plan also refers to Norway's goal of achieving climate neutrality by 2030.[174] Alongside the EU ETS, the Plan notes 'international cooperation on emission reductions, emissions trading, and project-based cooperation' as key mechanisms to deliver climate neutrality. Using international cooperation mechanisms like Article 6 of the Paris Agreement, Norway is developing 'pilots for market cooperation'. One such cooperation may be embodied by a Memorandum of Understanding signed between Norway and Senegal in November 2023. These developments could set the grounds for international CDR to be promoted as well.

O&G investments are still forecasted to increase alongside green investments. While a larger share of fossil fuels is being exported, emissions associated with O&G production and processing remain within Norway´s domestic emission reporting obligations. These dynamics will strongly affect Norway's decarbonisation trajectory in terms of the rate and magnitude of emissions reductions needed and may indirectly inform its CDR pathway in terms of the amount of money available for reductions and removals respectively (while noting that growth in O&G emissions cannot be scientifically justified through removals, and will simply necessitate deeper and faster emissions reductions at a later date).

Due to its relative wealth, Norway is in a strong position to absorb the costs of climate change mitigation, including carbon removals. In 2021, Norway's GDP was 442.7 billion USD, and it emitted 40.9 Mt of $CO_2$. This means that across the entire economy, 10,820 USD of GDP was generated per tonne of $CO_2$ emitted. A carbon price of 100 USD per tonne, levied across the entire economy, would amount to 4.1 billion USD, equating to 0.92% of the total size of the economy. Similar calculations can be done at different assumed carbon prices. The example below shows how much Norway would have to pay (in per cent of GDP) to cover its total $CO_2$ emissions (2021 baseline), based on an increasing carbon price (Figure 27).

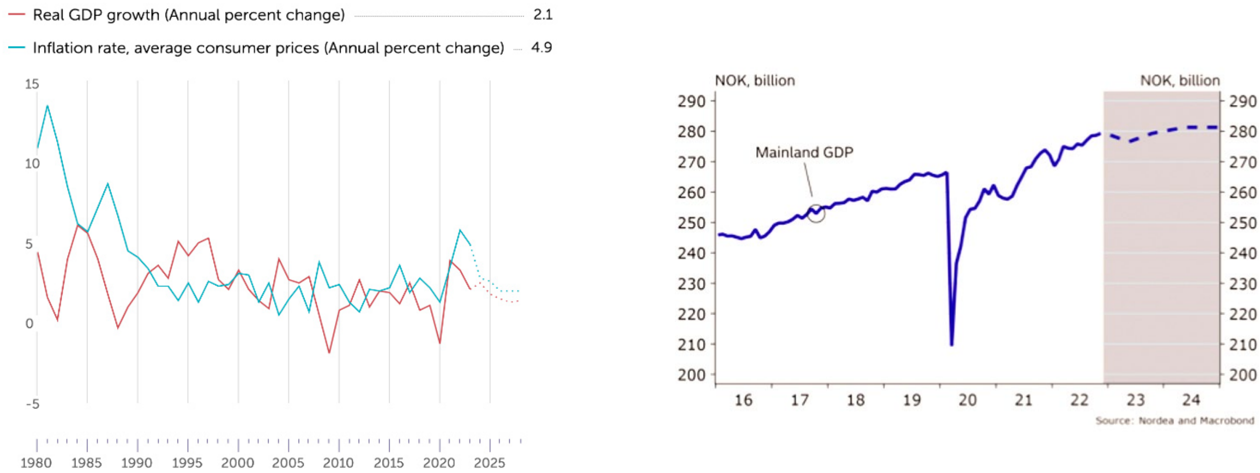



*Based on Norway's GDP in 2021 (442.8 billion USD) & $CO_2$ emissions in 2021 (40.92 $MtCO_2$)

**Figure 27: Carbon price point relative to total GDP %[175,176]**

172 European Commission (n.d.). *Our ambition for 2030.* https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/our-ambition-2030_en
173 Organization for Economic Co-operation and Development (OECD). (2022). *Carbon pricing in Norway.* www.oecd.org/tax/tax-policy/carbon-pricing-norway.pdf
174 Norwegian Ministry of Climate and Environment. (2022). *Norway's Climate Action Plan for 2021–2030.* www.regjeringen.no/contentassets/a78ecf5ad2344fa5ae4a394412ef8975/en-gb/pdfs/stm202020210013000engpdfs.pdf
175 Organization for Economic Co-operation and Development (OECD). (2022). *Norway.* https://data.oecd.org/norway.htm
176 Ritchie, H., et al. (2020). *$CO_2$ and Greenhouse Gas Emissions.* https://ourworldindata.org/co2-and-greenhouse-gas-emissions

According to the OECD, Norway's public spending remains very high, which is exacerbated by an ageing population and a need for increased productivity in public services. High interest rates and lower returns are also slowing contributions to the sovereign wealth fund, thereby limiting the potential for spending on new services. As such, Norway will have to remain vigilant with regards to the cost-benefit factor of its investments.




Source: IMF Data Mapper (2023)[177], Nordea[178]

**Figure 28: Real GDP growth and inflation rate in Norway (Left). Stagnation of economic activity (Right)**

Economic growth in Norway stagnated in 2023, with decreases in purchasing power due to inflation rates, with low growth expected at local and global levels (Figure 28). According to the OECD, Norway's mainland GDP growth was projected to slow to 1.2% in 2023. Similarly, the IMF predicts that GDP growth will slow down by 2028 (Figure 29). As a result of high inflation, strengthening of policies and a compressed labour market, output is expected to remain at 1.3% in 2024 (Figure 29).

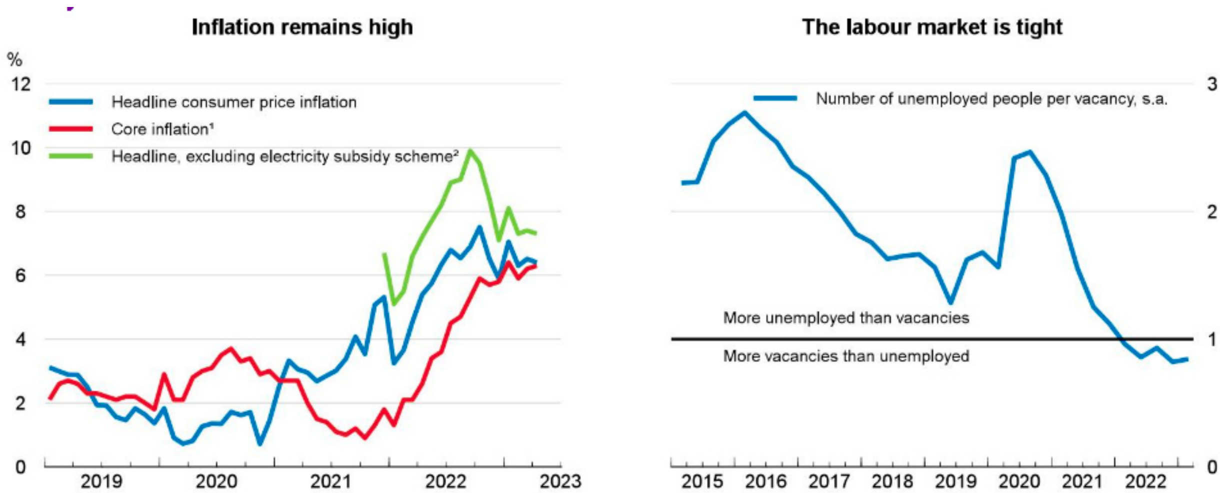



**Figure 29: Norway's high inflation rate and constrained labour market[179,180]**

177 International Monetary Fund (IMF). (n.d.). *Norway*. www.imf.org/en/Countries/NOR
178 Nordea. (2023). *Stagnation ahead for the Norwegian economy*. www.nordea.com/en/news/stagnation-ahead-for-the-norwegian-economy
179 OECD. (2023). *Development in individual OECD and selected non-member economies – Norway*. https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fstat.link%2Ffiles%2Fce188438-en%2F2ekd41.xlsx&wdOrigin=BROWSELINK
180 OECD. (2023). *Norway projection note, OECD Economic Outlook, Volume 2023, Issue 1.* Well trained technical staff would be required to develop and apply CDR, which is currently aggravated by the tight labour market. https://issuu.com/oecd.publishing/docs/norway-oecd-economic-outlook-june-2023?fr=sYmZhNzUwNTY2MTA

## 4.2. Human resources

The Norwegian Government aims for Norway to have a labour market in which employees enjoy security and flexibility, responsible employment practices. The Government's labour market policy is strongly aimed at a balanced and competitive economic and financial development, high labour force participation, inclusive labour market and workplaces, and low unemployment.[181]

There has been a sectoral shift from manufacturing to services (78.5%, see Figure 30), consisting mostly of business services, education, health, and social services. Notably, Norway has a political interest in attracting labour to the marine sector – which includes major ocean industries like maritime and seafood.[182] This is particularly important to sustain populations in remote areas, e.g., Northern Norway, where fisheries and aquaculture make a significant contribution to local communities, in terms of employment, value creation and tax revenues, but remain understaffed.[183] In this respect, marine CDR-related activities can gain public support by contributing to employment in coastal communities.

According to the OECD, over 30% of Norway's total workforce is employed by the Norwegian government, one of the highest proportions in the world, showing how the public sector acts as a significant source of demand for labour.[184] A similar report published by Menon Economics (2023), funded by the Ministry of Energy, showed that 5% to 6% of the total workforce either directly or indirectly employed in the petroleum sector in Norway in 2021.[185]

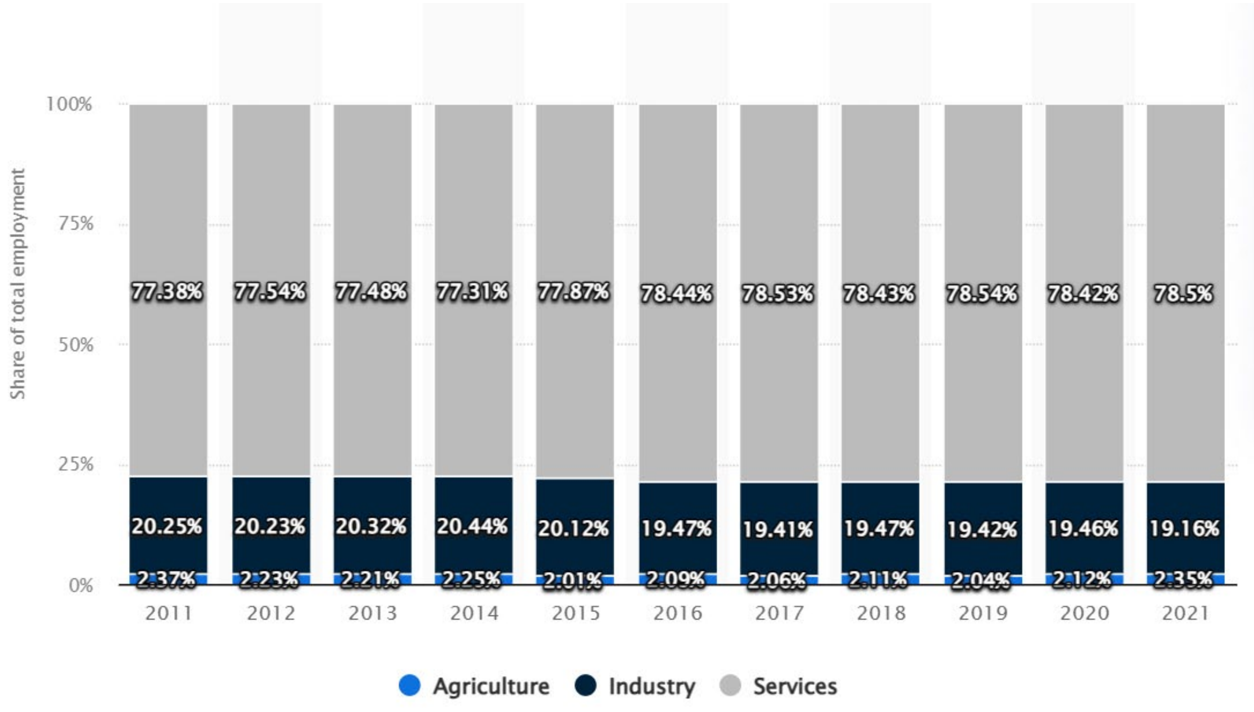



**Figure 30: Share of economic sectors in the GDP between 2011 and 2021[186]**

181 OECD. (2023). NORWAY – Recent policy developments and brief.
182 Norwegian Government. (2021). *The Government's commitment to the ocean and ocean industries.* www.regjeringen.no/en/dokumenter/the-governments-commitment-to-the-ocean-and-ocean-industries/id2857445/?ch=3
183 Nofima. (2023). *New report shows the Norwegian fishing industry is key for employment.* https://nofima.com/results/new-report-shows-the-norwegian-fishing-industry-is-key-for-employment
184 OECD (2023). *Government at a Glance 2023.* www.oecd.org/publication/government-at-a-glance/2023
185 Norsk Petroleum. (2023). *Employment in the petroleum industry.* www.norskpetroleum.no/en/economy/employment/#:~:text=A%20similar%20report%20published%20by,sector%20in%20Norway%20in%202021.
186 Statista. (2023). *Distribution of employment in Norway by economic sector from 2011 to 2021.* www.statista.com/statistics/327388/employment-by-economic-sector-in-norway


**Figure 31: Employed persons 15-74 years, by sex and industry division in 2022.[187]**

According to a European Labour Authority (ELA) report,[188] Norway has an insufficient number of workers with relevant skills in 250+ professions. Nearly half of Norwegian companies mentioned that more technical and engineering skills are needed in the workforce.[189] Similar expertise will be especially required if the country is to develop and deploy CDR at scale. The shortage of specialist technical workers is likely to continue in the short-term, as investment in training and recruitment develops.[190] The EU predicts that Norway's skills structure and population would not be able to fulfill the recruitment needs.[191]

Norwegian companies also have a high demand for expertise – for instance, tech-heavy associations such as Abelia and Energy Norway require 70% of their workforce to hold a master's degree.[192] However, Norway has made efforts to boost interest in technical studies and STEM jobs, by launching the Skills Policy Council and the Future Skills Needs Committee, developing new governance arrangements, and undertaking a collaborative project with the OECD to apply the OECD Skills Strategy in practice.[193]

Notably, there has been rapid growth in demand for green jobs in Norway. About 26% of Norwegian workers, across different skill levels, are involved in jobs with a significant proportion of green tasks (e.g., solar energy system engineers, refuse and recyclable material collectors).[194,195] Compared to the OECD average of 18%, Norwegian regions have higher shares of "green-task" jobs (Figure 32).

**187** Statistics Norway. (2023). *Employment, register-based.* www.ssb.no/en/arbeid-og-lonn/sysselsetting/statistikk/sysselsetting-registerbasert
**188** ELA. (2021). *Report on Labour Shortages and Surpluses.* www.ela.europa.eu/sites/default/files/2021-12/2021%20Labour%20shortages%20%20surpluses%20report.pdf
**189** TENKA. (2022). *Major lack of ICT and engineering expertise in Norwegian companies.* www.tekna.no/aktuelt/stor-mangel-pa-ikt--og-ingeniorkompetanse-i-norske-bedrifter
**190** Ibid.
**191** EURES. (2023). *Labour market information: Norway.* https://eures.ec.europa.eu/living-and-working/labour-market-information/labour-market-information-norway_en
**192** Oslo Business Region. (2023). *New report highlights the lack of competent tech talent in Norway.* https://tinyurl.com/2329p7dh
**193** OECD. (2014). *OECD Skills Strategy Norway.* https://www.oecd.org/skills/nationalskillsstrategies/Norway-Diagnostic-Report-Executive-Summary.pdf
**194** Based on classifications developed by O*NET for more than 900 occupations.
**195** OECD. (2023). *Job Creation and Local Economic Development 2023: Bridging the Great Green Divide.* https://t4.oecd.org/cfe/leed/NOR.pdf

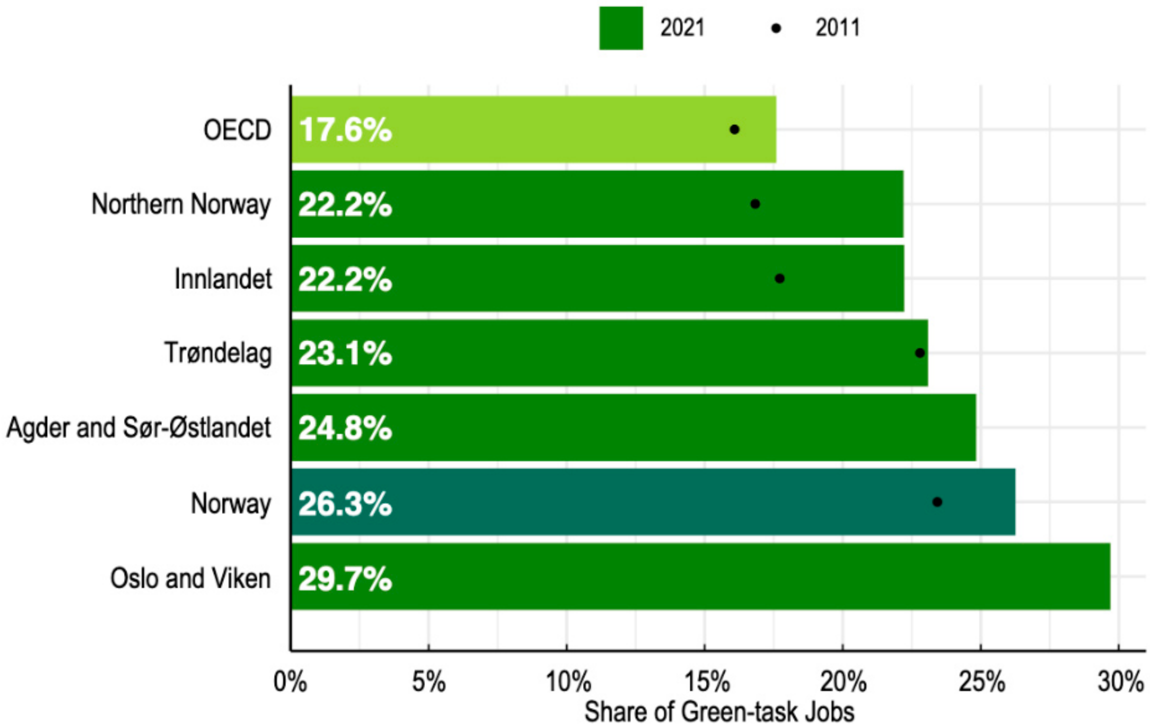



**Figure 32: Green-task jobs in Norway and OECD (2011-2021).**[196]

Further, in its Long-Term Low-Emission Strategy (LT-LEDS) submitted to the UNFCCC in 2020, Norway identifies itself in a strong position with a high participation rate in the labour market and a skilled workforce, offering a good starting point for absorbing new knowledge and technologies, potentially including CDR.

Norway's existing base of knowledge and expertise can serve as an enabling factor for CDR. For example, the O&G sector can provide technical competence regarding $CO_2$ value chains, transport, and storage, e.g., in existing oil wells on the Norwegian continental shelf.

## 4.3. Political / public landscape

As of late 2021, Norway has a minority centre-left coalition government between the Labour and Centre parties (such coalitions between the centre-left or right are commonplace in Norway). Leading up to the 2021 election, there was much speculation over the future of the economy, given its current focus on fossil fuels, with the possibility of the Labour party forming a coalition with the Greens for a majority share.[197]

While the Green party called for an end to oil exploration and production by 2035,[198] and a focus on renewable investment, Labour's coalition with the Centre party aborted this plan.

197 Lanteigne, M. (2023). *The Black, the Blue and the Green: Norway's Energy Dilemmas.* https://overthecircle.com/2023/01/09/the-black-the-blue-and-the-green-norways-energy-dilemmas
198 Adomaitis, N. (2021). *Climate change in election spotlight in oil giant Norway.* www.reuters.com/business/sustainable-business/climate-change-election-spotlight-oil-giant-norway-2021-08-31/

The release of the IPCC's report (www.ipcc.ch/report/sixth-assessment-report-working-group-i) on the irreversible impact of climate change, alongside the IEA's call for halting the exploration of new O&G projects,[199] put climate change at the forefront of political discussions in Norway. The 2021 election was dubbed the 'climate election', highlighting the widening tensions between Norwegians and their government.[200] Following the COVID-19 pandemic and the invasion of Ukraine, a spike in oil prices kept plans to defund petroleum exploration at bay. New drilling licenses were issued in 2022, and EU calls for a moratorium on Artic fossil fuel extraction have not yet made it into practice in Norway.[201] It will likely take decades to fully transition away from an industry that currently employs nearly 7% of the country's workforce and accounts for 20% of the economy.[202]

This transition could also indicate a chance for Norway to re-direct the workforce currently employed in O&G towards CDR. Several CDR methods build on similar technological know-how as O&G, especially with regards to operating and maintaining pipelines as well as geological $CO_2$ storage solutions (including geological surveying and sampling, MRV, and safety issues).[203]

## 4.4. Cultural, aesthetic, religious and ethical considerations

In Norway, public perceptions of climate change have changed gradually. The population is generally conscious of climate change, civically engaged, and aware of the need for climate solutions. However, a paradox exists between recognizing the necessity of climate action and the need for a national O&G industry. The majority of people support further exploration of O&G, while about one third advocate phasing out of O&G.[204] In a 2018 CICERO survey on Norwegians' stance on climate change, 67.4% acknowledged responsibility for reducing greenhouse gas emissions. However, there's a notable discrepancy in the level of support for different climate measures, with 52.7% opposing increased fossil fuel prices.[205] While environmental non-governmental organisations (ENGOs) lead the discussions on limiting O&G extraction, the Norwegian O&G industry has positioned itself as being environmentally responsible and responsive to public concerns. Equinor,[206] for example, is engaged in several initiatives related to CCS and/or CDR, including membership in the CCS+ Initiative and investment into a Norwegian CDR start-up.

### ENGOs and their positions on CDR

In Norway, ENGOs are generally supportive of nature-based solutions, including reforestation to sequester carbon. However, some ENGOs are sceptical of nature-based solutions. Friends of the Earth sees nature based solutions as locking in unsustainable practices and unjust power structures, while simultaneously not being an effective climate solution – also noting that they neglect the "transformative potential" of an "agroecology" approach that seek to address wider ecological, social, and economic aspects of the problem.[207] With regards to more "engineered" forms of CDR, the ENGO also expressed its concerns that Norway's CCS plans would cause delays in mitigation actions, through overreliance on a "distant future" technology. Greenpeace has strongly condemned Equinor's global projects, as the company ramped up its exploration licensing over the past decade.[208] In contrast, The Bellona Foundation and Zero – NGOs based in Oslo – are more open to engineered technologies. For instance, Bellona recently highlighted that "it is not enough to just reduce future greenhouse gas emissions. We must actively remove GHGs that are already present in the atmosphere and store the gases safely underground forever".[209] Bellona emphasizes the importance of using CDR for hard-to-abate sectors to address residual emissions.[210]

199 Reed, S. (2021). *To reach climate goals, new oil and gas investment must be stopped, energy agency says.* www.nytimes.com/2021/05/18/business/climate-change-report.html
200 The New Yorn Times. (2021). *Norway's 'Climate Election' Puts Center-Left in Charge.* www.nytimes.com/2021/09/13/world/europe/norway-climate-election.html
201 Bellona Europa. (2022). *Norway must accept an oil and gas-free Arctic.* http://tiny.cc/tiq9yz
202 Norwegian Petroleum. (n.d.). *The government' revenues.* www.norskpetroleum.no/en/economy/governments-revenues
203 Abouelnaga, M. (2022). *Engineered carbon dioxide removal: scalability and durability.* www.c2es.org/wp-content/uploads/2022/10/engineered-carbon-dioxide-removal-scalability-and-durability.pdf
204 CICERO. (2019). *Norwegian petroleum policy in a changing climate. Report 2019:10.* https://pub.cicero.oslo.no/cicero-xmlui/bitstream/handle/11250/2607906/Rapport%202019%2010%20Def%20-%20WEB.pdf?isAllowed=y&sequence=1
205 Ibid.
206 Equinor ASA (formerly Statoil and StatoilHydro) is a Norwegian state-owned multinational energy company headquartered in Stavanger
207 Friends of the Earth International. (2023). *Factsheets: 'nature based solutions' and soil carbon farming.* www.foei.org/publication/factsheets-nature-based-solutions-and-soil-carbon-farming
208 Greenpeace. (2023). *The truth about Equinor's global projects.* www.greenpeace.org/static/planet4-norway-stateless/2023/10/5e5e07a5-greenpeace-nordic_report-truth-about-equinors-global-projects_101023_web.pdf
209 Bellona Europa. (2021). *Norwegian industry calls for new carbon removal policy.* https://bellona.org/news/carbon-accounting/2021-11-norwegian-industry-calls-for-new-carbon-removal-polic
210 Bellona Europa. (2022). *Three basics for the EU to get CDR right.* https://bellona.org/news/eu/2022-05-three-basics-for-the-eu-to-get-cdr-right

### Norwegian culture and indigenous peoples

The relationship between landscape and cultural heritage interests has long been an issue in Norway. Specifically, the cultural and ethnic conflict with the Sami people has been highlighted since the deployment of wind power in Western Norway in 2010. The Roan and Storheia wind farms were developed as the largest onshore wind projects, but the Sami people opposed their installation as reindeer have been traditionally reared on the land. In 2021, the deployment of 151 wind turbines on reindeer pastures was considered a human rights violation by Norway's Supreme court. However, the wind farms remained in operation, which served to further deepen the conflict between the Norwegian government and the Sami people. Balancing the development of climate technologies, potentially including CDR, and their requirements for renewable power, and the interests of the indigenous people, will continue to be an area of debate that the Norwegian government must address.

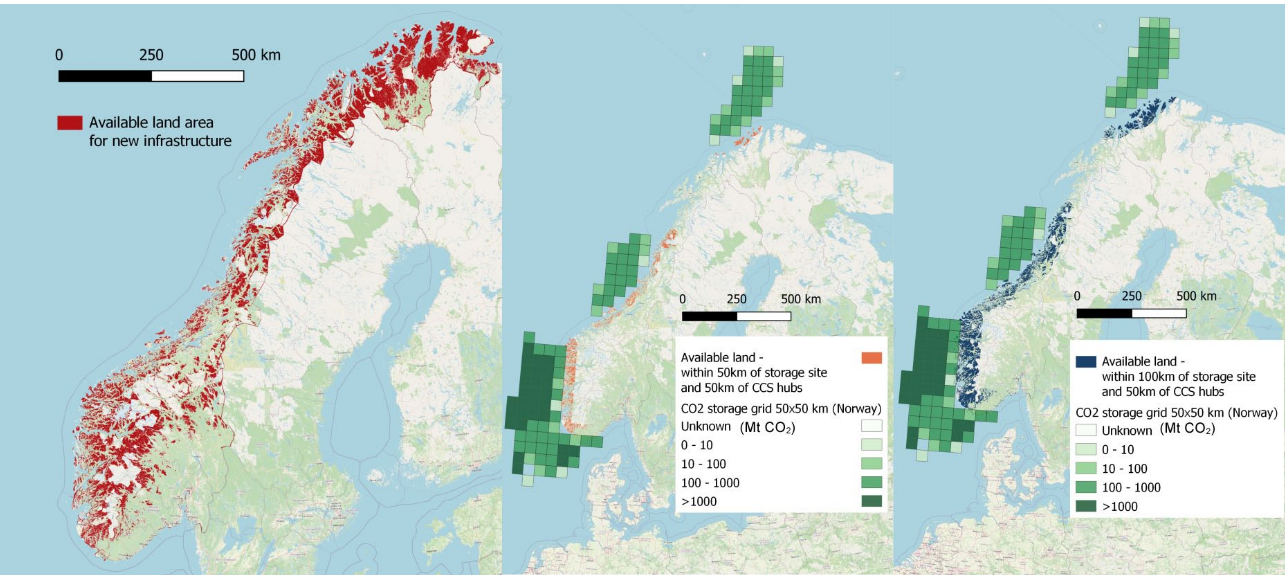
© Sebastien Goldberg – Unsplash

# 5. Theoretical potential for CDR deployment in Norway

### Land area assessment

To estimate the potential for land-based CDR in Norway, the available land area and potential locations of establishing new CDR technologies were identified. To do so, area occupied by (1) cities and infrastructure, (2) forests, (3) arable land, (4) wetlands, (5) water sources, and (6) protected and restricted cultural land, national parks and outdoor areas, were identified and "removed" from the landscape of Norway. This provided an "available" land area and locations where CDR technologies could be deployed. Figure 33 shows the available land area after removing the "unavailable" land areas specified above. Over 120,000 km$^2$ of land area could be available for deployment of CDR pathways. It is to be noted that this land area would also be used for any new infrastructure required to support the CDR pathways, for example, establishing new $CO_2$ pipelines, roadways, renewable electricity production facilities, thermal energy production facilities, etc.

For CCS-based CDR technologies, the distance to storage sites or $CO_2$ hubs is an important factor affecting the economics. Figure 33 shows total land area available for infrastructure development and the land area that falls within 50 km and 100 km of storage sites or CCS hubs.




(a) Area: ~121,000 km$^2$ (b) Area: ~14,000 km$^2$ (c) Area: ~40,000 km$^2$

**Figure 33: From left to Right: (a) Total available land area for infrastructure development in Norway (b) Available land area within 50km of storage sites or CCS hubs (c) Available land area within 100km of storage sites or 50km of CCS hubs.**[211]

At a high level, the available areas are ample space for developing both CDR pathways and the necessary infrastructure to support them. However, the sub-sections later in this report assesses the available land area in more detail, to identify suitable locations for a given CDR pathway. The sub-section below presents the energy availability in Norway and the assumptions made for estimating the CDR potential in Norway.

211 Carbon Limits Assessments using information from Miljødirektoratet, Hanssen-Bauer, I. et al. (2017). *Climate in Norway 2100*. https://www.miljodirektoratet.no/globalassets/publikasjoner/M741/M741.pdf

### Assumptions on thermal energy and electricity availability

Energy availability is the most significant constraint for several CDR deployment pathways. There are several studies on the projected electricity production and consumption in Norway. Studies on heat production capacities in Norway are limited. Section 2.1 summarized the different studies available on electricity production and consumption. Table 11 summarizes the assumptions used for estimating CDR potential in a low and high scenario.

| | 2030 (TWh/y) | 2040 (TWh/y) | 2050 (TWh/y) | Main source of information |
|---|---|---|---|---|
| **Low Scenario** | 7 – 15 | 11 – 40 | 16 – 37 | NVE (2021), Statnett (2021), Thema og Multiconsult (2022), DNV GL (2021), Prosess21 (2020) |
| **High Scenario** | 4 – 33 | 64 – 103 | 170 – 212 | Norsk Industri, Energy Transition in Norway (2022) |

**Table 11: Projected excess electricity in Norway between 2030 and 2050 in the low and high scenarios**

For production of thermal energy, very few studies are available on the estimated production and demand. The SINTEF paper (presented in Section 2.1 and Annex 4) estimates the biomass potential in Norway, if existing biomass in Norway is used efficiently. The estimates from SINTEF were used to develop a low and high scenario for thermal energy production in Norway. While SINTEF presents 3 scenarios, several policies need to be put in place for realizing these potentials. Hence the Business as Usual (BAU) scenario has been chosen for estimating the biomass potential in Norway. The potential stated for 2030 seems difficult to achieve within 6 years, hence this capacity has been assumed as achievable by 2050. By 2040, an assumption of 50% of this capacity is applied. Table 12 presents the summary of available biomass and the heat energy derivable from this capacity.

| | 2030 (TWh/y) | 2040 (TWh/y) | 2050 (TWh/y) | Main source of information |
|---|---|---|---|---|
| **Low Scenario** | 7 | 14 | 28 | SINTEF Energy Research, 2023 |
| **High Scenario** | 9 | 18 | 37 | SINTEF Energy Research, 2023 |

**Table 12: Projected excess thermal energy in Norway between 2030 and 2050 in the low and high scenarios**

Another approach to renewable heat generation is the use of electric furnace for producing heat using clean electricity. As per a report by McKinsey,[212] temperatures up to 400°C can be achieved using electric furnaces. In some cases, production of heat from electricity has been considered to assess the maximum CDR potential.

For other resources such as land, water and mineral availability, requirements are estimated based on the maximum deployment potential with energy availability as the main constraint. In all cases, availability of land, water or mineral has not been identified as a bottleneck for the assessed CDR pathways. This is detailed further in the sub-sections focussing on each CDR pathway.

212 Roelofsen, O. et al. (2020). *Plugging in: What electrification can do for industry*.
www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/plugging-in-what-electrification-can-do-for-industry

## 5.1. High-level theoretical potential for DACCS

To begin with, "All-In" scenarios with energy requirements as constraints were estimated. The following scenarios were developed for DACCS pathways. The CDR potential for DACCS in the 3 scenarios are summarized in Table 13.

- Scenario 1.1: low electricity production estimates are considered. Thermal energy for DACCS is also provided by electricity.
- Scenario 1.2: low electricity production estimates are considered. Thermal energy for DACCS is provided by biomass.
- Scenario 2: high electricity production estimates are considered. Thermal energy for DACCS is provided by a combination of excess electricity and biomass.

| Scenario | Pathway | TRL | 2030 (Mt $CO_2$/y) | 2040 (Mt $CO_2$/y) | 2050 (Mt $CO_2$/y) |
|---|---|---|---|---|---|
| Scenario 1.1 | *Electrochemical DACCS* | *4* | *10 – 20* | *16 – 55* | *23 – 51* |
| | S-DAC (low temp DAC) | 7-8 | 4 – 6 | 6 – 16 | 9 – 15 |
| | L-DAC (high temp DAC) | 7-8 | 3 – 5 | 5 – 13 | 8 – 12 |
| | *Mineral looping DACCS* | *3-4* | *4 – 7* | *6 – 18* | *8 – 17* |
| | *Humidity swing DACCS* | *3-4* | *22 – 46* | *34 – 123* | *49 – 114* |
| Scenario 1.2 | *Electrochemical DACCS* | *4* | *10 – 20* | *16 – 55* | *23 – 51* |
| | S-DAC (low temp DAC) | 7-8 | 4 – 5 | 9 – 10 | 19 – 20 |
| | L-DAC (high temp DAC) | 7-8 | 4 – 5 | 8 – 9 | 16 – 18 |
| | *Mineral looping DACCS* | *3-4* | *4 – 5* | *9 – 10* | *17 – 19* |
| | *Humidity swing DACCS* | *3-4* | *22 – 46* | *34 – 123* | *49 – 114* |
| Scenario 2 | *Electrochemical DACCS* | *4* | *6 – 46* | *95 – 143* | *252 – 293* |
| | S-DAC (low temp DAC) | 7-8 | 2 – 14 | 35 – 43 | 92 – 88 |
| | L-DAC (high temp DAC) | 7-8 | 2 – 11 | 32 – 34 | 84 – 71 |
| | *Mineral looping DACCS* | *3-4* | *2 – 15* | *34 – 47* | *90 – 96* |
| | *Humidity swing DACCS* | *3-4* | *12 – 102* | *198 – 318* | *523 – 653* |

**NOTE: These estimates are not cumulative as theoretical potential is estimated assuming all resources are dedicated to one technology exclusively. Hence, they show the total theoretical potential if all resources are assigned to them.*

**Table 13: DACCS potential in different scenarios between 2030 and 2050, with electricity and energy as constraints for different types of DACCS technologies – most likely potential in white cells.**

While estimates were performed for all DACCS pathways, pathways have differing levels of technology maturity. Liquid Solvent DAC (L-DAC) and Solid Sorbent DAC (S-DAC) have small scale commercial facilities set up today, with a TRL between 7 and 8.[213] As per the IEA's DAC report,[214] electro-chemical DACCS has a TRL of 4, but mineral looping and humidity swing have a TRL between 3 and 4. For the initial deployment phase, Norway should consider L-DAC and S-DAC as the predominant technologies to be deployed in Norway. Pilot studies and small-scale demonstration projects for electro-chemical, mineral looping, and humidity-swing DACCS are to be implemented before it is possible to develop more accurate estimates of technologies in Norway.

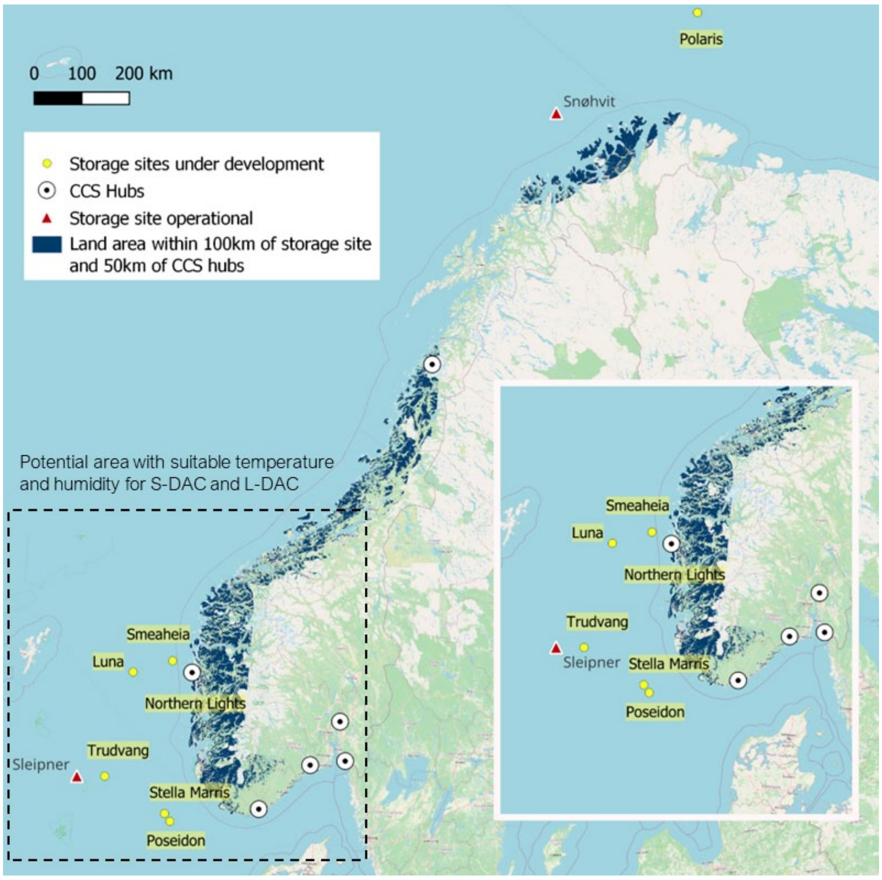
Ideally, a combination of electricity- and biomass-driven thermal energy production would work best in the case of Norway. The estimates presented are based on the assumption that all the excess biomass and electricity is dedicated to the operation of DACCS facilities. A realistic potential considering competing energy users must be done to estimate the realistic potential for DACCS in Norway.

213 Technology readiness levels (TRLs) are a method for estimating the maturity of technologies during the acquisition phase of a program. TRLs enable consistent and uniform discussions of technical maturity across different types of technology.
214 International Energy Agency (IEA). (2023). *Direct Air Capture.* **www.iea.org/energy-system/carbon-capture-utilisation-and-storage/direct-air-capture**

Furthermore, alongside the development of DAC facilities, the $CO_2$ storage areas for the captured $CO_2$ must be developed for the full potential of DACCS as a CDR method to be realized. As mentioned in Section 2.7, the total storage capacity of upcoming $CO_2$ storage projects is projected to reach 58 Mt per annum by 2030. Of this, 23 Mt per annum has been reserved by the planned $CO_2$ capture projects, leaving 35 Mt per annum of storage capacity available for future allocation. Focussing on S-DAC for L-DAC in 2030, the maximum estimates presented in the scenarios are well below 35 Mt per annum, meaning storage availability is not considered as a bottleneck for these scenarios to be realised.

In terms of other resources required for the deployment of L-DAC and S-DAC, the land area required and water required for the most intensive Scenario uses less than 2% of the land area available within 100km of storage sites and CCS hubs, and less than 0.1% of the water currently available in Norway (on average). Ensuring energy adequacy will thus be the biggest factor in DAC deployment in terms of resource requirements.

Another important aspect for the operation of L-DAC and S-DAC are the temperature and humidity considerations in the region. While a significant land area is available for DACCS deployment, a large part of Norway has average temperature below 0ºC for more than 4 months a year.[215] The humidity in these locations is typically higher than 55%, the ideal operating humidity for DACCS. The DAC facilities installed in Iceland recently had to pause operation due to low temperatures.[216] Figure 34 shows the area that could be ideal for deployment of DACCS, with suitable weather conditions typical in these areas for more than 9 months a year. Another option for DACCS deployment is the area around $CO_2$ hubs, for easier access to ports and high emitting industries. However, a more in-depth assessment of proximity to cities and residential areas is required to narrow down the suitable areas.




*Source: Carbon Limits Assessment using multiple sources*

**Figure 34: Potential area with suitable temperature and humidity for S-DAC and L-DAC**

215 Carbon Limits assessment using information from www.yr.no/nb
216 George, V. (2022). *World's Largest Carbon Removal Plant 'Orca' Freezes Over In Iceland.* https://carbonherald.com/worlds-largest-carbon-removal-plant-orca-freezes-over-in-iceland

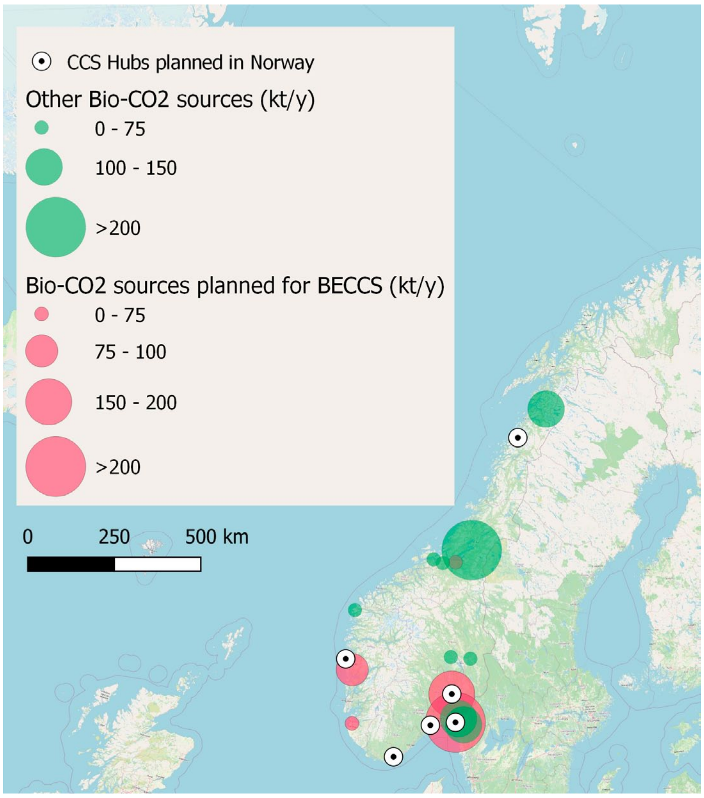
While this sub-section focused the findings predominantly on S-DAC and L-DAC, a more in-depth analysis of electrochemical, mineral looping and humidity swing DACCS would be required once more information and testing are carried out on these technologies.

## 5.2. High-level theoretical potential for Bio-CCS and biochar (using pyrolysis)

### Bio-CCS

Assessing the potential for biomass CCS uses some of the same sources of information that have been presented in the sub-section of DACCS. There are currently several sources of bio-$CO_2$ in Norway, that offer a "low hanging fruit" solution for capturing and storing this bio-$CO_2$. Figure 37 shows the distribution of facilities that emit over 50 kt of $CO_2$ every year that can be captured and stored as bio-$CO_2$. The facilities close to developing CCS hubs have made announcements for capture and storage of the bio-$CO_2$. More in-depth analysis of other bio-$CO_2$ source facilities and their proximity to CCS hubs or storage facilities needs to be done. Around 1.8 Mt$CO_2$pa can be captured with existing sources of bio-$CO_2$ in Norway. This can be targeted for 2030.

While assessing the potential for DACCS, the biomass growth potential as presented in the SINTEF paper was used to estimate thermal energy capacity. The same assumption was used in estimating the bio-CCS potential in Norway in 2040 and 2050 and the additional potential that could be developed in 2030. The 2030 estimate in the BAU scenario of the SINTEF paper is assumed as achievable by 2050, with 50% of the capacity achievable by 2040 and 25% by 2030. If this additional potential is achieved, the bio-$CO_2$ capacity in 2030 could range between 1.8-2.4 Mt$CO_2$pa based on existing facilities and additional potential as presented in the SINTEF paper assumptions. Table 14 below summarizes the technical potential in 2030, 2040 and 2050.




*Source: Carbon Limits Assessment using information from Miljødirektoratet*

**Figure 35: Sources of bio-$CO_2$ in Norway**

| | 2030 (Mt $CO_2$pa) | 2040 (Mt $CO_2$pa) | 2050 (Mt $CO_2$pa) |
|---|---|---|---|
| **Potential bio-$CO_2$ removals** | 1.8 – 2.4 | 4.0 – 5.0 | 9.0 – 10.0 |

**Table 14: Estimated bio-$CO_2$ that could be removed in Norway between 2030 and 2050 using Bio-CCS.**

Assessing whether the additional capacity would be incorporated at existing facilities using biomass or if new facilities will have to be developed is beyond the scope of this report. Further assessment is required on land area and infrastructure requirements for deploying bio-CCS in Norway.

### Biochar (using pyrolysis)

Biochar on the other hand is produced by burning biomass in lack of oxygen, using a process called pyrolysis. This biomass is converted to coal or "biochar" which is predominantly $CO_2$ in solid form. This biochar can be stored underground or in agricultural soil. An in-depth analysis of the advantages adding biochar to agricultural soil in Norway is beyond the scope of this report. However, the $CO_2$ storage potential of converting biomass to biochar can be estimated at a high level.

Using similar assumptions of achieving SINTEF's 2030 BAU estimate in 2050, and 50% and 25% of this amount in 2040 and 2030 respectively. The estimates presented for removal via bio-CCS, and removal through pyrolysis, both rely on using the full availability of biomass available in the identified scenario. Achieving the maximum potentials presented in this report for bio-CCS and pyrolysis is thus mutually exclusive, and these values should not be summed together – in reality some combination would be achievable by sharing these resources.

| | 2030 (Mt $CO_2$pa) | 2040 (Mt $CO_2$pa) | 2050 (Mt $CO_2$pa) |
|---|---|---|---|
| **Potential bio-$CO_2$ removals** | 0.8 – 1.1 | 1.6 – 2.3 | 3.2 – 4.6 |

**Table 15: Estimated bio-$CO_2$ that could be removed in Norway between 2030 and 2050 using pyrolysis.**

The produced biomass can be stored in soil – with co-benefits for improving soil conditions and benefits for cattle that graze on this land. However, this is topic of significant debate in Norway, where some stakeholders share concerns on the permanence of carbon storage in biochar. Norwegian soil conditions could degrade biochar, releasing $CO_2$ instead of storing it. More research is required to assess the performance of this type of storage, and the impacts on soil conditions in Norway.[217] Thus, the full potential stated in Table 15 represents a maximum, under the assumption that all carbon remains stored, when the likelihood is that less than 100% of the estimate will be achieved due to biochar degradation.

There is little information on the land area and other infrastructure requirements for bio-CCS and pyrolysis currently. Hence assessing the suitable areas for establishing new bio-CCS facilities or pyrolysis facilities is challenging. For Bio-CCS, ideally distance to storage location or CCS hubs is one of the main criteria, followed by proximity to users of thermal energy produced by these facilities. Assessing these requirements in the context of the Norwegian landscape would be important to provide more insights on the technical potential of Bio-CCS and biochar in Norway.

217 Conclusions from the workshop conducted for co-creating a roadmap for CDR Deployment in Norway.

## 5.3. High-level theoretical potential for weathering related CDR pathways

### Coastal enhanced weathering (CEW)

In coastal enhanced weathering (CEW), crushed minerals such as olivine are spread in coastal areas to be naturally weathered by the climatic conditions and proximity to water in the area. While no energy-intensive technology is required for the spreading of olivine, the mining and transport of olivine is an energy-intensive project. Norway has a very large deposit of olivine and is one of the largest producers of olivine in the world. On average, around 1 Mt of olivine is produced every year in Norway, with potential to produce up to 3 Mt per annum during years of high demand. As per an interview conducted with Sibelco (the only major olivine producer in Norway), up to 19 Mt of olivine can be produced every year in Norway, for the next 20 years. However, Sibelco also noted the importance of conducting an assessment of the sustainable rate at which olivine can be produced, while avoiding impacts to surrounding ecosystems due to mining processes.[218]

Chemically, 1 kg of olivine can capture 1.25 kg of $CO_2$. However, in realistic conditions, between 0.8 to 1 kg of $CO_2$ is effectively captured by 1 kg of olivine. Several Life Cycle Assessment (LCA) studies assess the electricity and water requirements of the CEW process from the mining of olivine to the spreading of olivine at coastal locations. However, the studies are very few and use European averages while estimating the requirements.[219] Studies specific to Norway are required to get a better understanding of resource requirements, especially since Norway currently has olivine production facilities in place.

Assessing the $CO_2$ capture potential using CEW is challenging at this stage, since there is very limited information on the re-use of area already spread with olivine for other purposes, or for further weathering processes. Furthermore, the olivine dissolution rate at 4°C is almost half the dissolution rate at 19°C, limiting the potential for colder countries.[220] Considering the coastal zones in Norway experience sub-zero temperatures at least for a few months a year, pilot testing of CEW in comparable regions is required to estimate the true $CO_2$ capture potential using CEW in Norway. As a further consideration, Norwegian stakeholders highlighted the risk of nickel content that will seep out during CEW process and pollute the surroundings.[221] More research is required to assess how to curb the seep out of nickel and what are the environmental effects of this nickel seeping out.

Norway has the world's second largest shoreline, extending over 100,000 km. However, there are 2 main restrictions to consider when assessing CEW potential: (1) protected areas along the shoreline – areas protected for ecosystem restoration, tourism, or other purposes, and (2) the suitability of available shoreline for the CEW process (for example, quality of soil, humidity, guarantee of olivine dissolution). Very few studies have been done in Norway to assess the shoreline availability for CEW. To provide a very high-level estimate, assuming 2-10% of this shoreline could be available and suitable for the CEW process, between 1-7 $MtCO_2$ could be removed using the CEW process. This would however require an additional 1.5 – 7.5 Mt of olivine for the process, in addition to the current production in Norway. This would lead to the consumption of between 0.1 -0.7 TWh of electricity, and up to 0.01 bcm of water, for the production of olivine, using the LCA estimates provided in a few studies. Furthermore, it is difficult to state whether this removal capacity could be met annually or over a longer/shorter period, as it will depend on the dissolution rate of the olivine in the water. Pilot projects are required to assess the pace of $CO_2$ removal from CEW process.

Pilot projects to assess the olivine dissolution rate, impacts on ecosystems, and suitability of Norwegian coastal zones for CEW, will be crucial in estimating a more realistic potential for CEW in Norway.

217 Conclusions from the workshop conducted for co-creating a roadmap for CDR Deployment in Norway.
218 Interview with stakeholder from Sibelco, Norway.
219 Foteinis, S. et al. (2023). *Life Cycle Assessment of Coastal Enhanced Weathering for Carbon Dioxide Removal from Air.* https://pubmed.ncbi.nlm.nih.gov/37011253
220 Pogge von Strandmann, P.A.E. et al. (2022). *The Dissolution of Olivine Added to Soil at 4°C: Implications for Enhanced Weathering in Cold Regions.* www.frontiersin.org/articles/10.3389/fclim.2022.827698/full
221 Interview with stakeholder from Sibelco, Norway

### Terrestrial enhanced weathering (TEW)

Terrestrial enhanced weathering (TEW), on the other hand, refers to the weathering on non-coastal areas, through the spreading of suitable minerals (crushed silicates), such as basalt. Crushed silicate minerals, on reacting with rainwater or humidity in air, could lead to permanent $CO_2$ locking in the area.[222] Arable land area is specifically considered suitable for terrestrial enhanced weathering, as this process has additional benefits such as reverse acidification of soils caused by farming practices.[223]

Around 2% of Norway's land area is considered arable land. In terms of basalt availability, large amounts of basalt were deposited in Norway millions of years ago, both on- and off-shore. Over 100 basalt flows have also been identified in the Norwegian Sea, however, estimates on the quantity of reserves are yet to be done.

To provide a very high-level estimate, assuming all the arable land is used for terrestrial enhanced weathering, around 7,123 $km^2$ of land area would be available for TEW. Most pilot projects assume a density of mineral spreading of around 2 kt of basalt per $km^2$ of land area (20 tonne per hectare).[224] For use in Norwegian arable land, this would require over 14 Mt of basalt for TEW, which could lead to between 3.5-4.4 $MtCO_2$ captured from the atmosphere. However, it is difficult to state whether this removal capacity could be met annually or over a longer/shorter period. Pilot projects are required to assess the pace of $CO_2$ removal from TEW process.

It is to be noted that the sequestration potential in TEW is highly dependent on (1) soil pH, (2) soil type and size of particle, (3) humidity and temperature in the area, and (4) rainfall in the area. There are very few case studies worldwide estimating the $CO_2$ sequestration potential of TEW using models that investigate the weathering process and $CO_2$ sequestration capacity over time. The rate of basalt dissolution varies over time, hence the $CO_2$ sequestered will vary accordingly. The estimate provided above does not take into consideration these aspects, due to lack of information in the Norwegian context. An in-depth pilot study with a "soil baseline" assessing the pH, type of soil, and other factors is required to estimate the realistic potential of TEW in Norway.

Furthermore, the impacts of TEW on arable land, on the type of crops grown in Norway, on the groundwater system, and on animal grazing on these lands must be assessed, to ensure the ecosystem is not affected due to TEW implementation.

All in all, the estimates for CEW and TEW provided in this section a very high-level, however they do indicate that Norway has a potential to explore these nature-based pathways for $CO_2$ removal and sequestration. It is too early to estimate a national level capacity for these solutions, and more region-specific pilot studies are required to develop a methodology and model for assessing the $CO_2$ removal potential.

## 5.4. High-level theoretical potential for forestry-related CDR pathway

Deforestation occurs when existing forest areas are felled and converted for other land use. Development of infrastructure and housing are the biggest sources of deforestation in Norway. Yet trees play a very important role in capture of $CO_2$ from the atmosphere using the natural photosynthesis process. Two strategies can be used for increasing forest cover in Norway. Afforestation refers to planting of trees in areas which previously did not have a forest cover, and reforestation refers to planting of trees in areas that were previously classified as forest areas. It is essential to note that the effectiveness of trees in $CO_2$ removal depends on various factors, including tree species, forest management, ecosystem health, and climate conditions. Furthermore, in Norwegian weather conditions (in the north), it takes between 60 and 120 years before trees are mature for cutting – that is, they have absorbed their full potential for $CO_2$ storage.[225] Hence, estimation of $CO_2$ capture potential from forestry-related activities can be challenging, with gross approximations.

222 Vienne, A. et al. (2022). *Enhanced Weathering Using Basalt Rock Powder. Carbon Sequestration, Co-benefits and Risks in a Mesocosm Study With Solanum tuberosum.* https://www.frontiersin.org/articles/10.3389/fclim.2022.869456/full
223 Beerling, D. and Long, S. (2018). *Guest post: How 'enhanced weathering' could slow climate change and boost crop yields.* https://tinyurl.com/3t9h479t
224 The Future Forest Company. (2021). *Enhanced Weathering of basalt rock as a method of atmospheric $CO_2$ removal.* https://assets.publishing.service.gov.uk/media/6281f42ae90e071f646c6b43/the-global-future-forest-report.pdf
225 Halldorsson, G. et al. (2008). *Affornord: Effects of afforestation on ecosystems, landscape and rural development.* https://norden.diva-portal.org/smash/get/diva2:701703/FULLTEXT01.pdf

Large scale afforestation projects were initiated in Norway in the 1950s and 1960s, with predominantly spruce trees planted in the areas. However, from 1980s, the rate of afforestation has decreased due to lower economic support from the government and lower prices of wood vs increased cost of labour.

Studies in Norway show significant potential linked to afforestation on overgrown areas and reforestation in areas that were previously classified as forested area. A report by Miljødirektoratet in 2013 presented the land area that could be available for reforestation and afforestation in Norway. After assessing the overall land area available, a series of categories (such as distribution of vegetation type in the region, category of "felling class" of forest area, terrain steepness) was used to narrow down the land area that could be suitable for reforestation and afforestation.[226] In the period 2015-2018, a pilot study was conducted to plant spruce trees in this land area identified by Miljødirektoratet. However, more stringent land area assessment was done for the pilot study, introducing additional requirements to the 2013 estimate, such as (1) suitability for the growth of spruce trees, (2) restriction to open areas with early growth potential, (3) high production capacity and low negative change on albedo, (4) restriction to areas not important for biodiversity. The additional criteria also ensured the planting takes place in areas that are not important for natural diversity, outdoor interests, important cultural-historical values or valuable cultural landscapes. The areas estimated by Miljødirektoratet in 2013 and in the subsequent pilot phase are summarized in Table 16. The additional requirements significantly reduced the area available for the pilot phase. By the end of the pilot phase, only around 6,000 Dacres (6 $km^2$) had been planted in the three pilot counties.[227] This is expected to capture 700 kt of $CO_2$ over the next 85 years. Miljødirektoratet has estimated the total potential for afforestation on overgrown areas with "acceptable effects on biodiversity and other environmental values" to be 190 $km^2$, with an annual potential of 9 $km^2$ over a 20-year period.[228]

| Area type | Area estimated by Miljødirektoratet in 2013 ($km^2$) | Area estimated in pilot phase report by Miljødirektoratet ($km^2$) |
|---|---|---|
| **Area suitable for reforestation (land area fulfilling the forest definition)** | 8,440 | 1,370 |
| **Area suitable for afforestation (land area not fulfilling the forest definition)** | 1,340 | 620 |
| **Total area** | **9,780** | **1,990** |

**Table 16: Total potential area for reforestation and afforestation in Miljødirektoratet report in 2013 and their report on the pilot phase in 2019**

While the estimated area where planting could take place is large, with the additional criteria to significantly increase the climate benefits are added, it becomes challenging to identify suitable areas. The pilot phase report by Miljødirektoratet highlights the potential goal conflicts at the intersection between forestry, agriculture and the environment. The pilot phase highlighted a need for an increased focus on conditions linked to inactive agricultural land, such as the relationship with soil conservation and environmental values in nature types that depend on care.[229]

However, the Norwegian government is currently preparing a subsidy plan aimed at reforestation and afforestation in overgrown and inactive agricultural land. The plan is expected to identify locations for potential planting and quantify the area of suitable land. It is unlikely that additional reforestation and afforestation beyond what is being planned by the Norwegian government could be enacted in Norway, considering the difficulties identified in the pilot phase document. The subsidy plan being developed by Norway is in line with reducing the average age of forests in Norway. In addition, a new support mechanism, providing subsidies for afforestation of new areas, is currently under consideration in Norway by the Norwegian Environment Agency and the Norwegian Agriculture Agency, along with accompanying guidelines.[230]

226 Miljødirektoratet (2013). *Planting av skog på nye arealer som klimatiltak* www.miljodirektoratet.no/globalassets/publikasjoner/M26/m26.pdf
227 Miljødirektoratet . (2019). *Pilotfasen for 'Planting av skog på nye areal som klimatiltak'* www.miljodirektoratet.no/globalassets/publikasjoner/m1161/m1161.pdf
228 Zero. (2023). *$CO_2$-fjerning – Løsningen som tar oss til null.* https://zero.no/wp-content/uploads/2022/10/Co2_fjerning_rapport_nettside.pdf
229 Miljødirektoratet . (2019). *Pilotfasen for 'Planting av skog på nye areal som klimatiltak'* www.miljodirektoratet.no/globalassets/publikasjoner/m1161/m1161.pdf
230 Landbruksdirektoratet. (2023). *Jord og jordhelse.* www.landbruksdirektoratet.no/nb/jordbruk/miljo-og-klima/jord-og-jordhelse

Furthermore, a crucial aspect highlighted during the stakeholder workshop is the difference between reforestation and improved forest management (or restoration). While restoration goes beyond mere planting of trees, a more concrete plan is required by the Norwegian government to assess if $CO_2$ removal from forestry related activities is considered additional.

Bogs are low oxygen wetlands that are created by the accumulation of organic material, where the area can get waterlogged. These wetlands can bind $CO_2$ per unit area, through plant photosynthesis and by acting as sediment traps for runoff.[231] Around 10% of Norway's land area is covered by bogs and wetlands. They are very important for ecosystems and are important habitats for a number of species. When bogs are drained, the available land is used for agriculture or forestry. The draining of bogs releases vast amounts of $CO_2$ into the atmosphere.

In Norway, conversion of bogs in the period 1990-2020 has led to total emissions of over 10 Mt $CO_2$. Nibio has estimated that a ban on the cultivation of all bogs could lead to a reduction in $CO_2$ emissions of 0.2 to 0.6 Mt by 2050 (cumulative). However, preventing the conversion of bogs is considered $CO_2$ avoidance, not $CO_2$ removal. It is nevertheless mentioned because it is an important measure to cut emissions and preserve important ecosystems.[232]

**Box 2: Restoration of wetlands and bogs**

## 5.5. High-level theoretical potential for ocean-based CDR pathways

Oceans play a pivotal role in absorbing substantial amounts of $CO_2$ for biological sequestration. The absorptivity of oceans can be improved in several ways, for example using algae-based carbon capture and sequestration or by improving the alkalinity of oceans for better $CO_2$ absorption. While research on ocean-based CDR is still novel, there is evidence that oceans can play a crucial role in nature-based CDR.

### Kelp farming

Kelp farming refers to the cultivation, harvesting and sequestration of kelp. Kelp absorbs $CO_2$ during photosynthesis and stores carbon in its biomass. This biomass, when stored, can be a source of $CO_2$ removals. Kelp can also help with reducing ocean acidification, as a result of $CO_2$ absorption, but the environmental effects of growing large scale kelp farms is yet to be studied. Norway currently holds 15% of global wild seaweed production.[233] The sea area inside the Norwegian maritime baseline covers 89,091 km$^2$. Having the second-longest coastline in the world gives Norway an enormous potential for kelp cultivation at sea.[234] The sea areas outside Nordland, Trøndelag, and Møre og Romsdal counties have proven to be the most suitable for growing seaweed (Figure 36).[235]

231 MBWSR. (2923), *Carbon Sequestration in Wetlands.* http://tiny.cc/i3y9yz
232 Zero. (2023). *$CO_2$-fjerning – Løsningen som tar oss til null.* https://zero.no/wp-content/uploads/2022/10/Co2_fjerning_rapport_nettside.pdf
233 FAO. (2021). *The global status of seaweed production, trade and utilization.* https://www.fao.org/3/ca1121en/ca1121en.pdf
234 Edvardsen, A., and Almås, K. A. (2017). *Norsk havøkonomi mot 2050.* https://sintef.brage.unit.no/sintef-xmlui/handle/11250/2456384
235 Norderhaug, K. et al. (2020). *Ecosystem-level effects of large-scale disturbance in kelp forests.* www.researchgate.net/publication/343087337_Ecosystem-level_effects_of_large-scale_disturbance_in_kelp_forests

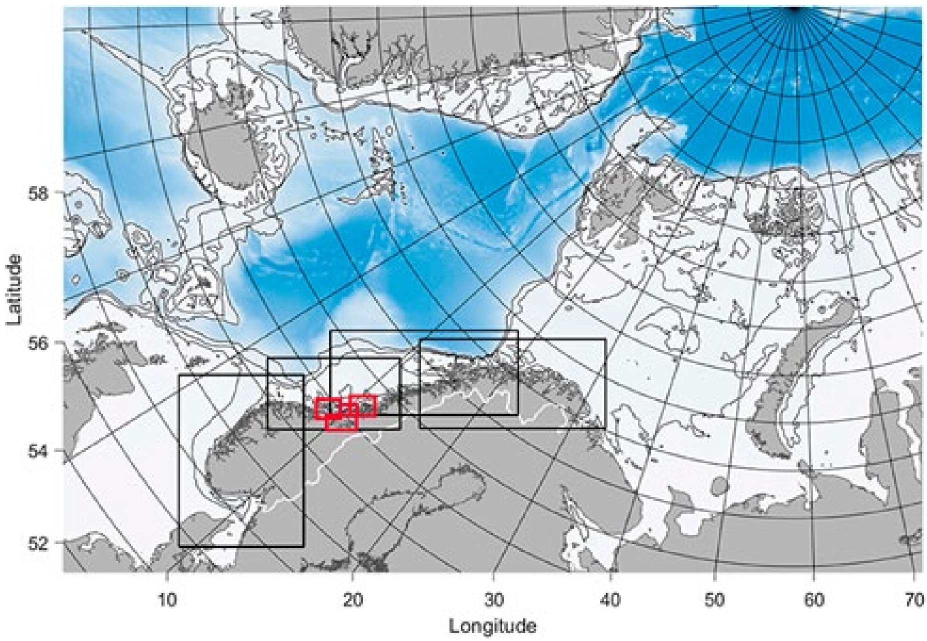



**Figure 36: The sea areas most suitable for growing seaweed[236]**

A study done by Broch et al. assessed the seaweed cultivation potential in Norwegian coastal regions (Figure 37).[237] The maximum cultivation potential was estimated to be 15 – 20 kt/ km²/ year.[238]

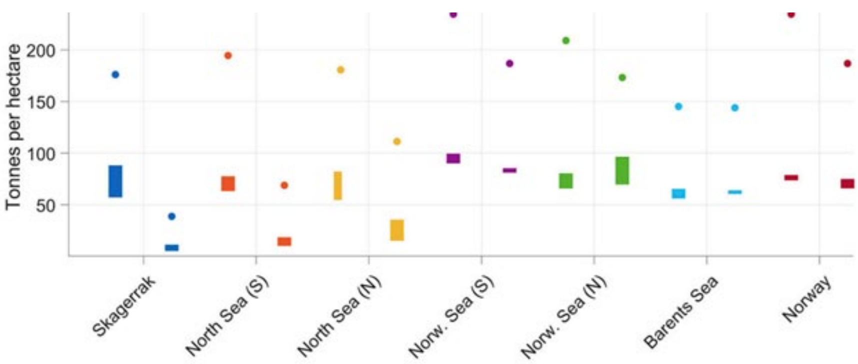



**Figure 37: Cultivation potential within Norwegian coastal ecoregions[239]**

There is little difference between deploying in autumn (September, left bars) versus late winter (February, right bars). Deployment in September yielded similar averaged and maximum values throughout all the regions, though with a peak in the Norwegian Sea regions.

As of 2020, there are 106 sites in Norway with permits to grow seaweed. The total area of 9.25 km² can yield about 130 kt of seaweed (wet weight) (Figure 38).

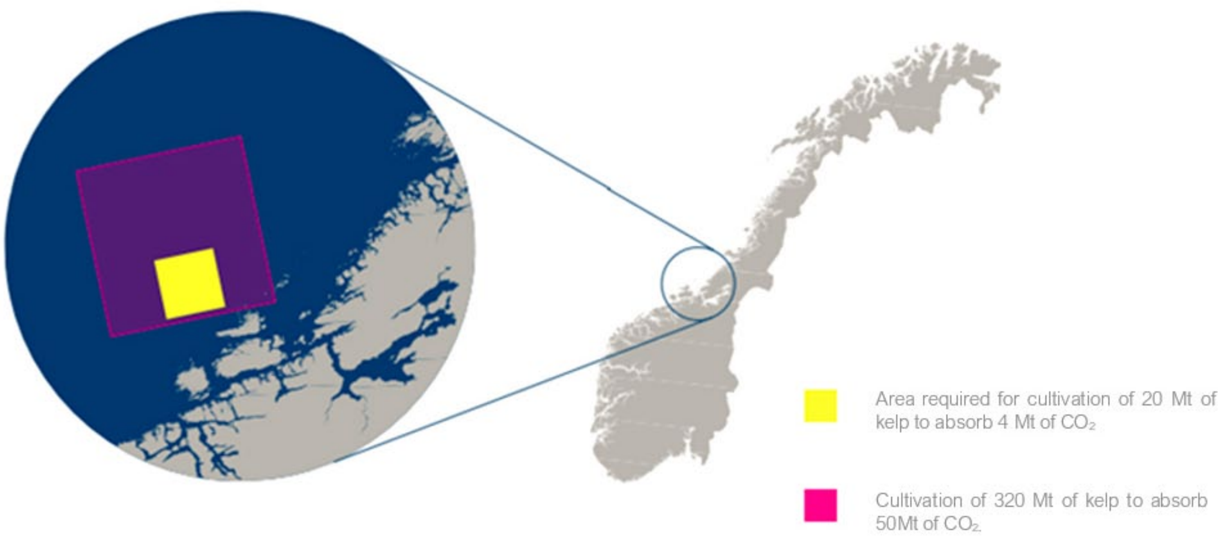
236 Edvardsen, A., and Almås, K. A. (2017). *Norsk havøkonomi mot 2050.* https://sintef.brage.unit.no/sintef-xmlui/handle/11250/2456384
237 Broch, O. et al. (2019). *The Kelp Cultivation Potential in Coastal and Offshore Regions of Norway.* https://kelppro.net/onewebmedia/Broch%20etal%202019%20Kelp%20cultivation%20potential%20in%20Norwegian%20coastal%20and%20offshore%20regions.pdf
238 Bremnes, H. et al. (n.d.) *Exploring the potential in large-scale seaweed cultivation.* https://mrfylke.no/content/download/18730/206339?version=1
239 Broch, O. et al. (2019). *The Kelp Cultivation Potential in Coastal and Offshore Regions of Norway.* https://kelppro.net/onewebmedia/Broch%20etal%202019%20Kelp%20cultivation%20potential%20in%20Norwegian%20coastal%20and%20offshore%20regions.pdf

| County | Number of companies | Area ha[1)] | The year the first licence was granted 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | Total sites |
|---|---|---|---|---|---|---|---|---|---|---|
| Agder | 3 | 13 | | | | 1 | | 1 | 3 | 5 |
| Møre og Romsdal | 8 | 101 | 1 | | | 2 | 4 | 1 | 2 | 10 |
| Nordland | 15 | 206 | | 4 | 4 | 3 | 1 | 5 | 4 | 21 |
| Rogaland | 3 | 6 | | 1 | | | 1 | | 1 | 3 |
| Troms og Finnmark | 4 | 29 | | | | 1 | 1 | | 1 | 3 |
| Vestland | 20 | 453 | 6 | 9 | 7 | 6 | 13 | 8 | 2 | 51 |
| Trøndelag | 4 | 117 | 4 | 3 | 2 | 1 | 3 | | | 13 |
| **Total** | **57** | **925** | **11** | **17** | **13** | **14** | **23** | **15** | **13** | **106** |

*1 ha = 0.01 $km^2$ = 10,000 $m^2$*

*Source: Bremnes, H. et al.*

**Figure 38: The area of seaweed cultivation and the year the permit was granted, divided into counties.**




*Source: New opportunities for value creation in Norway (in Norwegian)*

**Figure 39: Areas for kelp production required for $CO_2$ capture.**

*Seaweed Carbon Solutions* (DNV, SINTEF, Equinor and Lundin) was launched in April 2022. The pilot project will run until the end of 2024, and the commercial upscaling phase should commence in 2025, with one or more major installations off the coast of Trøndelag in central Norway. The project has funding of more than 30 million NOK over three years. SINTEF estimates that removing 2,500 t of $CO_2$ requires about 20,000 t of seaweed to be grown across an area of 1 $km^2$. Capturing 5 Mtpa of $CO_2$ (12% of Norway's total annual emissions) requires 2,000 $km^2$ of the ocean surface to be covered with seaweed farming installations. The variety used in the pilot project – sugar kelp – can grow by more than 1 cm per day. For comparison, each new tree planted today may need 20 to 30 years to achieve its full $CO_2$-capturing potential.

**Box 3: Seaweed Carbon Solutions pilot project.**

Norway has good natural conditions for such farms along most of the coast, and especially offshore, where the temperature and nutrient supply is more stable than coastal areas.[240] The estimated seaweed production potential (e.g., kelp) off the coast of Norway is 20 kt/km²/year, which could capture 2.5-3.0 kt$CO_2$/km²/year.[241] It has been estimated that by 2050 up to 20 Mt of kelp could be produced cumulatively by the Norwegian aquaculture industry, capturing between 6 – 9 Mt$CO_2$ pa. Using the average kelp production potential in Norway, this would require an area of 2,700 - 3,000 km². While this sounds low in comparison to the 89,091 km² of maritime baseline in Norway, there are several competitors for this land area.

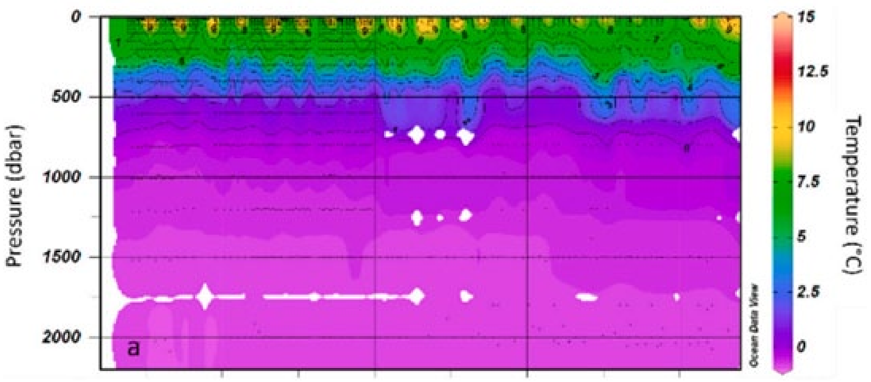
Kelp farming is dependent on sunlight to grow, demanding large areas of dedicated land for its farming. Even though the Norwegian coast is long, space is limited and there is competition with fishing, trawling, restoration and conservation activities and ensuring boat traffic access. Furthermore, there is little information on other infrastructure requirements for kelp farming, such as energy requirements and human resource requirements for large scale kelp farming. While power demand is estimated to be quite low compared to other CDR pathways, power is needed at farms for monitoring devices, fuel for boats, energy for a dwelling associated with the farm, automated system to raise/lower lines, floating cabins for temporary housing, lighting for safety, navigation, security, or dwellings.[242] More geographic research is required to assess what land area could be dedicated to kelp farming in Norway. Lastly, after the kelp is produced, it is important to store this captured $CO_2$ permanently. Two possible ways of storing this $CO_2$ are yet to be tested with kelp:

- Biochar: The harvested seaweed undergoes a pyrolysis process, after which it is mixed with composted seaweed and soil and then used as a soil enrichment supplement. The process produces eco-friendly and nutrient-rich fertiliser, at the same time ensuring that carbon is stored safely and securely in the soil.
- Storage on the seabed: The harvested seaweed is sunk to the bottom of the sea in areas more than 1,000 metres deep. At such great depths, there is little mixing with the surface water, so the material remains captured in the sediment. This means that the $CO_2$ will not be released back into the atmosphere.

More research and pilot projects are required to assess sequestration using biochar and natural/forced storage of kelp on the ocean seabed.

### Ocean Alkalinity Enhancement (OAE)

Ocean alkalinity enhancement (OAE) on the other hand is an approach involving adding alkaline substances to seawater to enhance its alkalinity, leading to more $CO_2$ absorption from the atmosphere. The efficiency of OAE processes depends on $CO_2$ concentrations in seawater, and the pH of the seawater. Over the years, the characteristics of Nordic Sea areas have changed with increasing temperatures (Figure 40) and decreasing pH (Figure 41) as the most prominent factor.[243]



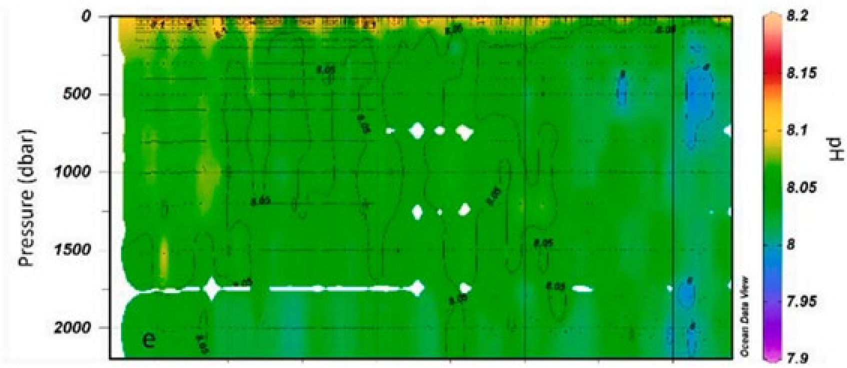

The figure depicts the change in the temperature of ocean water over the period 1993-2003. The left axis "Pressure" is related to ocean depth.

*Source: Monitoring Ocean acidification in Norwegian seas, 2019*

**Figure 40: Increase in surface temperature of ocean water in Norwegian Sea (2019).**

240 Sørensen, A. et al. (2022). *Negative Emissions and Carbon Dioxide Removal (CDR) Including Ocean Scenarios.* www.ntnu.edu/documents/1276062818/1283878281/ntnu_rapport_negativeemmisions_web.pdf/85f9e489-33ec-27c9-fe56-95ed48e309f2?t=1655988639531
241 Broch, O. et al. (2019). *The Kelp Cultivation Potential in Coastal and Offshore Regions of Norway.* https://kelppro.net/onewebmedia/Broch%20etal%202019%20Kelp%20cultivation%20potential%20in%20Norwegian%20coastal%20and%20offshore%20regions.pdf
242 Rose, D.J. and Grear, M.E. (2022). *Marine Renewable Energy Applications for Restorative Ocean Farming: Kelp.* www.pnnl.gov/main/publications/external/technical_reports/PNNL-32776.pdf
243 Miljødirektoratet. (2020). *Monitoring ocean acidification in Norwegian seas in 2019.* www.miljodirektoratet.no/globalassets/publikasjoner/m1735/m1735.pdf

In the 200-plus years since the industrial revolution began, the concentration of $CO_2$ in the atmosphere has increased due to human actions. During this time, globally, the pH of surface ocean waters has fallen by 0.1 pH units (Figure 41), which represents approximately a 30% increase in acidity (since the pH scale is logarithmic).




The figure depicts the change in the pH levels of ocean water over the period 2001-2021. The left axis "Pressure" is related to ocean depth.

*Source: Monitoring Ocean acidification in Norwegian seas, 2019*

**Figure 41: pH of water column in Norwegian Sea (2019)**

There are several factors which could justify OAE in Norwegian ocean/waters:

- Due to the alkaline properties of sea water, considerably larger amounts of $CO_2$ can be dissolved in sea water compared to fresh water;
- Colder sea water can take up more atmospheric $CO_2$ than warmer water;
- Colder water is denser and sinks to the bottom of the sea, which means deeper waters contain more $CO_2$.

One way of increasing ocean alkalinity is by **ocean liming**. Limestone (or calcium carbonate) is used in the ocean liming process, but it has to be processed to produce Calcium Hydroxide ($Ca(OH)_2$), that is then added to the seawater. Limestone is mined and processed to produce Calcium Oxide (CaO) and then $Ca(OH)_2$, which is finally spread in the ocean to uptake $CO_2$ from the atmosphere. Once added to seawater, the Calcium Hydroxide reacts with acid in the seawater and neutralizes it, forming a carbonate ion. The effect is a boost in alkalinity to the ocean, and greater ocean alkalinity means more $CO_2$ can be absorbed.

Between 1.6 – 2.0 t of limestone would be required to remove 1 $tCO_2$ from the atmosphere. The land requirements are low, as per the scientific papers assessing the LCA of the ocean liming process, but are highly dependent on where the production is taking place.[244] Norway produces between 5-6 Mtpa of limestone and has the capacity to produce more.[245] However limited information is available on what quantity can be sustainably produced every year to understand the excess limestone that could be dedicated to ocean liming use.

The LCA assessments on ocean liming undertaken to date consider the full process, from the mining of limestone to the spreading of CaO in ocean. The electricity and thermal energy required take these steps into consideration too. Considering an excess electricity of between 7 – 15 TWh/year (as used in the "low scenario – 2030" DACCS estimation, see Table 11) and thermal energy excess of 7 TWh/y (low scenario – 2030, see Table 12), between 6.5- 8.5 Mt of additional limestone can be produced for ocean liming every year (thermal energy is the constraining factor in this estimation). This could lead to the removal of 4-5 $MtCO_2$ from the atmosphere. However, it is difficult to state whether this removal capacity could be achieved annually or over a longer/shorter period. Pilot projects are required to assess the pace of $CO_2$ removal from ocean liming process.

244 Foteinis, S. et al. (2022). *Life cycle assessment of ocean liming for carbon dioxide removal from the atmosphere.* www.sciencedirect.com/science/article/pii/S0959652622028955
245 Norge Geologiske Undersøkelse (NGU). (n.d.). *Kalkstein.* www.ngu.no/om-geologi/kalkstein

It is to be noted that this estimate is very high level and assumes all of the excess thermal energy that could be available, based on SINTEF's biomass potential in 2030 and the excess electricity, goes into production of limestone. Achieving the maximum potentials presented in this report for DACCS and ocean liming is thus mutually exclusive, and these values should not be summed together – in reality some combination would be achievable by sharing these resources. Several other constraining factors, such as competition for this thermal energy for non-CDR activities and pace of increasing mining of limestone, should be taken into consideration for assessing the realistic potential. Incorporating these more detailed constraints is beyond the scope of this report, hence future studies and interviews with stakeholders working in the limestone production sector would be required to do an in-depth analysis.

There are two more important aspects to highlight while estimating a more realistic potential for ocean liming in Norway:

1. The production of CaO from limestone itself results in the production of $CO_2$. This $CO_2$ needs to be captured and sequestered underground for the process to be net negative. This could be in direct competition with DACCS and Bio-CCS, both of which require $CO_2$ storage sites. A prioritization study is required to assess which pathway leads to more $CO_2$ removal compared to the resources and infrastructure used.
2. There are limited pilot studies on actual $CO_2$ capture potential in oceans. Most studies assume a homogenous alkalinity change in ocean surface water, but the reality could be different. Supersaturation of surface ocean water with calcium and carbonate ions could lead to precipitation and "reverse" the $CO_2$ capture potential. The low water temperatures in winter and the movement of ships could affect the alkalinity as well. The feasibility of ocean liming is likely to be a function of application rate, precipitation rate, and surface ocean turnover.[246] Pilot studies in suitable areas of Norway would be required to estimate a more realistic potential.

Apart from direct ocean liming, electrochemistry could help with increasing the ocean alkalinity. In the **electrochemical $CO_2$ removal process**, water from the ocean is drawn into a tank where electricity is used to rearrange water and dissolve salts into acidic and basic components. Returning the basic solution to the ocean can help increase the alkalinity of ocean water, leading to more $CO_2$ absorption. Research is currently ongoing on the use of the acidic solution produced in this process. Several uses have been identified for this acidic solution but have not been tested at a pilot scale yet.

The theoretical potential of electrochemical $CO_2$ removal is immense, while using only electricity and sea water as the main resources. Currently there is very little information on the land area required for establishing a pilot facility or for estimating the land area required per tonne of $CO_2$ removed from the atmosphere. The requirement of electricity also varies drastically in the papers that present this process. While already demonstrated at lab scale, pilot testing is required to get a good estimate on electricity requirements for this process, in Norwegian weather conditions. Co-locating offshore wind production and electrochemical facilities has been presented as a novel idea that could increase renewable energy capacity in the country, while removing $CO_2$ from the atmosphere. Such ideas are currently under development but would require significant research to assess the true potential.[247] Due to the low availability of data, the theoretical potential for electrochemical $CO_2$ removal in Norway is not estimated in this report. Norway with its large coastal area could prove to be an ideal test bed for electrochemical $CO_2$ removal. Furthermore, the effect on ecosystems of increasing ocean alkalinity must be studied at the location of implementation, to provide more context to the scale at which it could be deployed.

## 5.6. Case study optimization of selected CDR pathways

It is evident that not all the surplus electricity and thermal energy available will be allocated to CDR operations. Estimates of excess electricity also vary significantly between sources, prompting the assessment of a few case studies to prioritize resources. While a comprehensive optimization for all CDR pathways is beyond the scope of this report, two case studies have been conducted to optimize bio-CCS, S-DAC, and L-DAC, identified as the most probable technological CDRs for deployment in Norway. The following sections provide descriptions of these case studies and their respective findings, focusing on the low-hanging fruit among the assessed CDR pathways.

246 Renforth, P. et al. (2013). *Engineering challenges of ocean liming.* **www.sciencedirect.com/science/article/pii/S0360544213006816**
247 Sharifian, R. et al. (2020). *Electrochemical carbon dioxide capture to close the carbon cycle.* **https://pubs.rsc.org/en/content/articlepdf/2021/ee/d0ee03382k**

Both case studies have different assumptions on resource dedication for CDR purposes. The assumptions on percentage of excess electricity and thermal energy that can be dedicated for CDR purposes aims to highlight the importance of dedicating energy resources to CDR, and show the potential of CDR, if such energy resources are made available for operating CDR.

### Case study 1

The low estimates (see Section 5: Assumptions on thermal energy and electricity availability for more information) of electricity and thermal energy availability are considered in the first case study. On electricity, 50% of the available excess electricity is marked CDR initiatives. On the other hand, thermal energy allocation for district heating and cooling remains relatively steady (as presented in Section 2.1), with a potential for increased electrification. Hence the first case study assumes up to 75% of the excess thermal energy could be directed towards CDR efforts. Given that Bio-$CO_2$ is a low-hanging fruit for Norway, it is implemented to its fullest extent as presented in Section 5.2 and any surplus energy is allocated to implementing both S-DAC and L-DAC technologies. Higher prioritization is given to S-DAC, considering the familiarity of deploying S-DAC in Iceland, a country with similar (albeit colder) climatic conditions as Norway.

| | 2030 (Mt $CO_2$pa) | 2040 (Mt $CO_2$pa) | 2050 (Mt $CO_2$pa) |
|---|---|---|---|
| **Potential bio-$CO_2$ removals** | 1.8 – 2.4 | 4.0 – 5.0 | 9.0 – 10.0 |
| **Potential for S-DAC** | 2.5 - 3.0 | 5.0 - 6.0 | 10.0 - 11.5 |
| **Potential for L-DAC** | 1.0 - 2.0 | 4.0 – 5.0 | 2.5 – 5.0 |
| **Total potential** | **5.3 - 7.4** | **13.0 - 16.0** | **21.5 - 26.5** |

*Underlying assumptions are that 50% of the electricity from the "low scenario" and 75% of thermal energy is available for bio-CCS, S-DAC and L-DAC operations. See Section 5 for resource assumptions*

**Table 17: Optimization of bio-CCS, S-DAC and L-DAC in case study 1**

### Case study 2

The high estimates (see Section 5: Assumptions on thermal energy and electricity availability for more information) of electricity and thermal energy availability are considered in the second case study. On electricity, 50% of the available electricity is assumed to be allocated for CDR operations. Thermal energy requirements are assumed to be fulfilled with a combination of excess thermal energy available and electricity. Given that Bio-$CO_2$ is a low-hanging fruit for Norway, it is implemented to its fullest extent as presented in Section 5.2 and any surplus energy is allocation 50% - 50% to S-DAC and L-DAC. Table 18 below summarizes the potentials estimated in Case study 2.

| | 2030 (Mt $CO_2$pa) | 2040 (Mt $CO_2$pa) | 2050 (Mt $CO_2$pa) |
|---|---|---|---|
| **Potential bio-$CO_2$ removals** | 1.8 – 2.4 | 4.0 – 5.0 | 9.0 – 10.0 |
| **Potential for L-DAC** | 0.5 – 1.5 | 4.0 – 4.5 | 8.5 – 10.5 |
| **Potential for S-DAC** | 0.5 – 1.8 | 4.0 – 5.5 | 10.5 – 11.5 |
| **Total potential** | **2.8 – 5.7** | **12.0 – 15.0** | **28.0 – 32.0** |

*Underlying assumptions are that 50% of the electricity from the "high scenario" is available for bio-CCS, S-DAC and L-DAC operations. See Section 5 for resource assumptions.*

**Table 18: Optimization of bio-CCS, L-DAC and S-DAC in case study 2**

The case studies illustrate that alongside the implementation of bio-CCS, allocating between up to 50% of excess electricity to DACCS could result in the removal of approximately 20 to 30 Mt of $CO_2$ from the atmosphere annually by 2050. While further assessment of the feasibility of dedicating these resources to DACCS is warranted, the findings suggest that Norway has the potential to extend its efforts beyond bio-CCS implementation and emerge as a pivotal player in CDR deployment across Europe.

## 6. Evaluation of CDR pathways with Norway's goals

| CDR Pathway | Theoretical potential in time horizon ($MtCO_2$) | Time horizon summary & assumptions | Further assessment |
|---|---|---|---|
| **DACCS – S-DAC** | **2030:** 2 – 14<br>**2040:** 6 – 43<br>**2050:** 9 – 88 | Potential per year – for all scenarios combined | Monitoring of new electricity and thermal energy capacities is important to develop a more realistic potential. Pilot testing to assess suitable areas (based on climatic conditions) is required to find areas for DACCS deployment. Further analysis on electrochemical, mineral looping and humidity swing DACCS required once more testing is carried out on these technologies. |
| **DACCS – L-DAC** | **2030:** 2 – 11<br>**2040:** 5 – 34<br>**2050:** 8 – 71 | Potential per year – for all scenarios combined | |
| **DACCS – L-DAC** | **2030:** 1.8 – 2.4<br>**2040:** 4.0 – 5.0<br>**2050:** 9.0 – 10.0 | Potential per year – for all scenarios combined | Assess whether the additional capacity would be incorporated at existing facilities using biomass or if new facilities will have to be developed. Further assessment is required on land area and infrastructure requirements for BECCS. |
| **Biochar** | **2030:** 0.8 – 1.1<br>**2040:** 1.6 – 2.3<br>**2050:** 3.2 – 4.6 | Potential per year – for all scenarios combined | As more information on land area and other infrastructure requirements for biochar is available, assess the suitable areas for establishing pyrolysis facilities. |
| **CEW** | 1 – 7 | Estimate for a batch process – unclear whether annual or less/ more frequent. Assuming 2-10% of shoreline availability. | Pilot projects are required to assess the pace of $CO_2$ removal from CEW process and suitability for Norwegian shoreline. |
| **TEW** | 3.5 – 4.4 | Estimate for a batch process – unclear whether annual or less/ more frequent. Assuming all the arable land is used and density of spreading around 2 kt of basalt per $km^2$. | Pilot projects are required to assess the pace of $CO_2$ removal from CEW process and suitability for Norwegian shoreline. |
| **Afforestation or Reforestation**<br>. | Not estimated | - | Between 1,990- 9,780 $km^2$ of land could be available for afforestation or reforestation. This could be compared to the area receiving subsides for reforestation/ afforestation to estimate further potential. |
| **Kelp farming** | 6 – 9 Mt $CO_2$ | Potential per year by 2050 – Assuming seaweed production of 20 kt/$km^2$/year by 2050 | More geographic research is required to assess what area could be dedicated to kelp farming. More research required to assess sequestration using biochar and natural/ forced storage of kelp on the ocean seabed. |
| **Ocean liming** | 4 – 5 Mt $CO_2$ | Estimate for a batch process - Assuming excess electricity and thermal energy as used in the "low scenario – 2030" for DACCS estimation | Pilot projects are required to assess the pace of $CO_2$ removal from ocean liming process. |

| CDR Pathway | Theoretical potential in time horizon ($MtCO_2$) | Time horizon summary & assumptions | Further assessment |
|---|---|---|---|
| **Electrochemical $CO_2$ removal** | Not estimated | - | Theoretical potential is immense, while using only electricity and sea water as the main resources. Norway with its large coastal area could prove to be an ideal test bed for electrochemical $CO_2$ removal. |

**Table 19: Summary of estimated theoretical potential in Norway for CDR pathways assessed.**

Based on the high-level theoretical potential estimated, bio-CCS and DACCS rank higher on the list since they are technologically more advanced than other CDR pathways, and the reductions are more traceable compared to nature-based solutions.

While the case studies focus on bio-CCS and DACCS, kelp farming is another CDR pathway that is highly relevant for Norway due to the country's prior experience in kelp production and the availability of ocean area for kelp farming. Reforestation also has a good potential in Norway, provided there is ample monitoring of the forest health. This ranking is relatively in line with the findings from the workshop, where stakeholders placed priority on bio-CCS, DACCS, reforestation, improved forest management, biochar, and blue carbon (or kelp farming) as the most politically relevant CDR methods for Norway. Stakeholders also raised the issue of permanence when it comes to reforestation and improved forest management.

Owing to the multiple bio-$CO_2$ sources existing in Norway, bio-CCS is a "low-hanging" opportunity for Norway. If biomass production is optimized, as presented in the SINTEF paper, bio-CCS potential and production of biochar can be improved significantly in the country. Collaboration on bio-CCS at the Nordic level also has a significant potential, considering Sweden and Finland both have ample sources of bio-$CO_2$. Storage sites in Norway could be used for storing bio-$CO_2$ from the Nordic region.

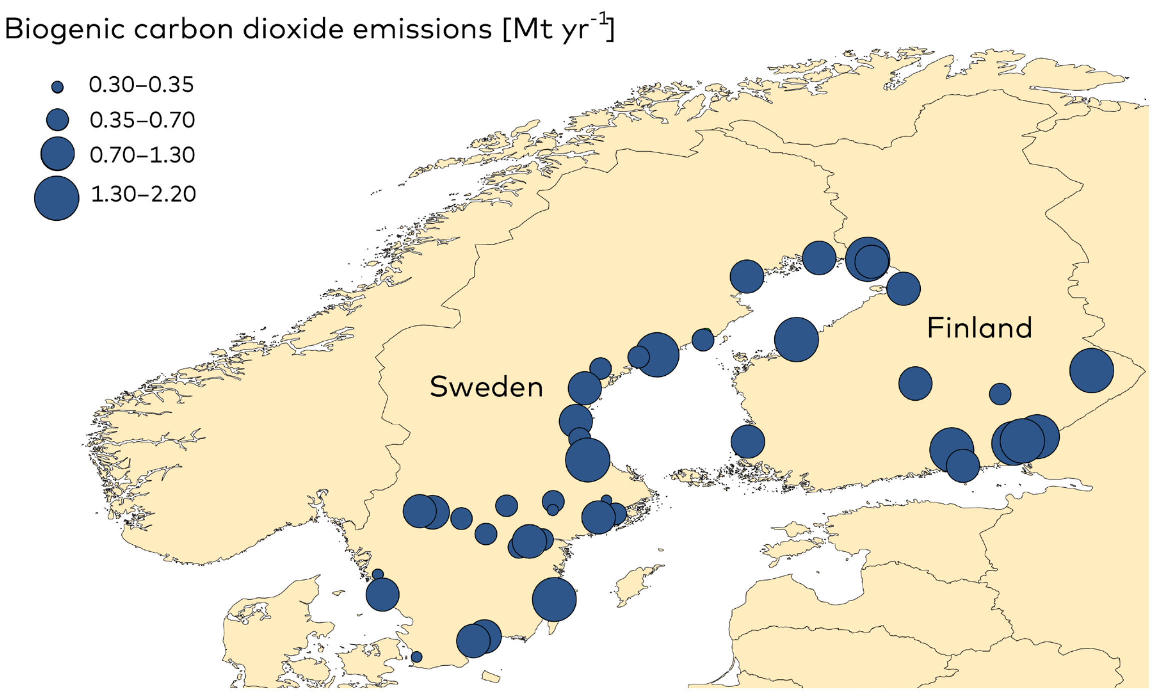



**Figure 42: Bio-$CO_2$ sources in Sweden and Finland[248]**

248 Nordic Council of Ministers. (2021). *Policies for the promotion of Bio-CCS in the Nordic countries.* www.norden.org/en/publication/policies-promotion-beccs-nordic-countries

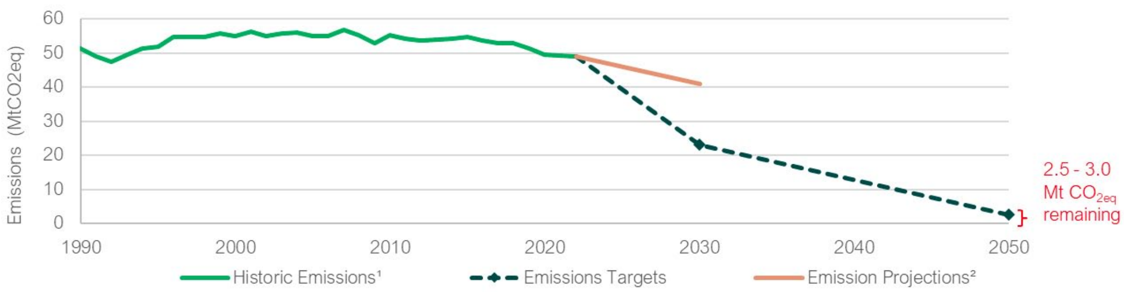
Implementation of DACCS, specifically S-DAC and L-DAC, have significant potential in Norway, provided electricity and thermal energy production is increasing in the country. Norway has a significant potential to increase its renewable energy capacity. Development of CDR pathways are highly dependent on the pace at which renewable energy capacities are developed in the country. Initiating pilot projects in areas with suitable weather conditions will help assess the realistic potential for DACCS in the country.

Kelp farming is another promising CDR pathway for Norway, offering potential for substantial scaling. Northern Norway, with its cool seawater and long hours of daylight during summer has a significant potential for kelp production.[249] While the country has significant ocean seabed for kelp farming, competitive uses of this seabed and waterway must be explored to estimate a realistic potential for $CO_2$ removal.

Reforestation on the other hand has a high scope yet high variability for $CO_2$ removal in Norway. The Norwegian government is currently preparing a subsidy plan aimed at reforestation and afforestation in overgrown and inactive agricultural land. In addition, a new support mechanism providing subsidies for afforestation of new areas is currently under consideration in Norway.[250] It is unlikely that additional reforestation and afforestation could be enacted in Norway (beyond what is already planned by the Norwegian government), considering the difficulties identified in the pilot phase document presented in Section 5.4.

### How do these findings relate to Norway's emission reduction plan?

Figure 43 depicts historical emissions in Norway, as well as future emissions reduction targets and emissions projections based on existing climate policies. Current projections estimate that under existing national climate policy, Norway will achieve only a 20% reduction in emissions by 2030, in contrast to the national target of 55%. Based on the emission reduction targets set by Norway, by 2050 Norway will still have 2.5-5 $MtCO_2eq$ to curb to reach net-zero. This is comparatively a small quantity considering the high-level CDR potential in Norway. A combination of the low-hanging bio-CCS potential and Norway's reforestation plan could be sufficient to reach net-zero.




[2] *2030 emissions projected based on existing Norwegian climate policies submitted to the European Environment Agency in 2021. Source: Climate Action Tracker.* ***https://climateactiontracker.org/countries/norway/targets***

[3] *Includes expenditures for the protection of air and climate in public administration under the: purchase of goods and services, salary costs, capital wear and tear, environmental protection investments, transfers abroad, other transfers, and subsidies. Source: SSB* ***https://ssb.no/statbank/table/12456/tableViewLayout1***

**Figure 43: Historic emissions, emission projections and emission targets in Norway from 1990 to 2050**

But the significant CDR potential in Norway could help the country go beyond net-zero and remove more $CO_2$ from the atmosphere provided the infrastructure development is also improving at a rate required for CDR deployment. To put emissions in context, Norway's oil and gas exports are estimated to generate 400-500 Mt $CO_2$ of combustion emissions in importing countries.[251] This is very large compared to Norway's annual emissions. Furthermore, owing to its $CO_2$ storage capacity potential, Norway could also be a net $CO_2$ importer to help store $CO_2$ removed/captured in other countries. This underlines the critical importance of policy alignment and infrastructure enhancement to harness Norway's substantial capacity for CDR and effectively contribute to global climate change mitigation efforts.

**249** The Nofima notebook. (2020). *Kelp farming: a great opportunity for northern Norway and the world.* **https://thefishsite.com/articles/kelp-farming-a-great-opportunity-for-northern-norway-and-the-world**
**250** Landbruksdirektoratet. (2023). *Jord og jordhelse.* **www.landbruksdirektoratet.no/nb/jordbruk/miljo-og-klima/jord-og-jordhelse**
**251** Only $CO_2$ emissions associated with burning natural gas, assuming 90% natural gas purity and 100% combustion. Between 1.6 to 2.2 kg $CO_2$ assumed to be emitted per $m^3$ of natural gas.

# Annex 1: More information on thermal energy production and consumption in Norway

In 2028, households and the service industry consumed respectively about 38 TWh and 16 TWh of energy for heating and cooling. The industrial sector consumed about 19 TWh of heating and cooling in 2018, with over 50% of the heat coming from fossil fuels.[252] The heat produced for district heating and cooling is on the other hand predominantly fuelled by bioenergy – waste (45%) and from bark, wood chips and wood (35%). In 2009, when a landfill ban was introduced, many new waste incineration plants and district heating plants were established. In 2022, the amount of district heat supplied to consumers amounted to 6.7 TWh.[253]

Geothermal capacity currently installed in Norway use ground source heat pumps (GSHP) for delivering heat directly to its users. In residential building, converting from electric heating or district heating to GSHP is considered expensive. Hence, the investments flowing into geothermal capacity expansion in Norway are expected to be low.[254] While there is consideration for reusing abandoned hydrocarbon wells for geothermal energy production for partially electrifying the offshore industry, it directly competes with platform electrification via offshore wind power or direct cables from onshore Norway. The current focus and research in geothermal space in Norway is on improving the efficiency of existing geothermal facilities and increasing the depth of boreholes for increasing production capacities.[255]

In the case of biomass used for producing heat, a recent paper by SINTEF estimates a high potential for production of sustainable biomass by optimising the use of existing sources of bioenergy in Norway.[256] As per the SSB, approximately 26 TWh of bioenergy (biofuels, waste, use of district heating and share of electricity coming from thermal energy) was consumed in Norway in 2022. Using the biomass feedstock estimated by SINTEF, the bioenergy use can be increased by almost 20 TWh/year, if the accumulation of said sources of biomass could be done economically and sustainably.

Biomass can also be used as a feedstock in smelting industry, which could be a direct competitor to use of biomass for thermal energy production. Norsk Industri (The Federation of Norwegian Industries) released a roadmap for the decarbonization of process industries in 2016, where they state the importance of biomass in decarbonization. Carbon is typically used as a reducing agent in several process industries. Theoretically, carbon from renewable sources such as charcoal produced from pyrolysis, and wood chips can replace fossil coal. If pyrolysis of biomass is economically viable, the byproduct could be used in the industrial sector.

© Vidar Nordli Mathisen – Unsplash

252 Norwegian Water Resources and Energy Directorate (NVE). (2023). *Varme.* www.nve.no/energi/energisystem/termisk-energi/varme
253 Statistisk Sentralbyrå. (2023). *District heating and district cooling.* www.ssb.no/en/energi-og-industri/energi/statistikk/fjernvarme-og-fjernkjoling
254 Gehlin, Signhild. (2019). *Geothermal energy use in the Nordic countries.* www.rehva.eu/rehva-journal/chapter/geothermal-energy-use-in-the-nordic-countries
255 Muller, Jiri for IEA Geothermal. (2023). *2022 Country Report Norway.* https://iea-gia.org/about-us/members/norway/#:~:text=Norway%20is%20a%20young%20nation,GJ%20per%20year%20of%20energy.
256 Carbon Limits analysis using information from SINTEF paper: Everson, N. et al. (2023). *What is the potential of BioCCS to deliver negative emissions in Norway? From biomass mapping to a window of negative emissions potential.*

## Annex 2: Multiconsult's analysis on offshore wind potential in Norway

**An analysis from Multiconsult for the Norwegian Offshore Wind organization shows that it is possible to develop 338 GW of offshore wind in Norway.[257] As of today, the Norwegian government's target is 30 GW by 2040.**

However, due to the social acceptability of some renewable energy installations and the rate of development of policy for the support of renewable energy development. Norsk Industry used DNV's global forecast, the Energy Transition Outlook (ETO) and model to present a single-scenario best estimate of electricity generation in Norway until 2050. It takes into account the geo-political conditions, policy enhancement, development in technologies and associated costs and behavioural aspects to the development of renewable energy in Norway.

The report presents that future onshore installations are likely to be delayed and/or scaled down by public concerns like noise, impact on birds, recreation, and a desire to preserve untouched landscape and wilderness.

Furthermore, the Norwegian public is wary of building excess capacity for export to other European countries, fearing it would increase the domestic costs of electricity.

Hence most of the wind energy development will be offshore, constituting 80% of 200 TWh wind-based generation in 2050.


*Source: Figure from BCG,[258] using information from NVE,[259] 2023*

**Figure 44: 300 GW of offshore wind possible in the areas suggested by the Norwegian Water Resources and Energy Directorate (NVE).**

257 Multiconsult (2023). www.norwegianoffshorewind.no/news/new-report-possible-to-build-338-gw-of-offshore-wind-in-norway
258 Hjorth, R. et al. (2023). *Norway's 300 GW offshore wind opportunity.* https://media-publications.bcg.com/norways-300-gw-offshore-wind-opportunity.pdf
259 Norwegian Water Resources and Energy Directorate (NVE). (2023). *Identification of assessment areas for offshore wind.* https://veiledere.nve.no/havvind/identifisering-av-utredningsomrader-for-havvind/kart/interaktivt-kart

# Annex 3: Additional information on water resources in Norway

The condition of Norway's natural water resources, including the ocean, coastal waters, and freshwater, ranges from "fairly good" to "good" based on the Norwegian Environment Agency's Nature Index.[260] The national water regulation, Vannforskriften, implements the EU Water Framework Directive to protect (and where necessary, restore to at least "good" condition) surface water and groundwater resources.[261,262] Approximately 20,000 km of stormwater pipelines and 39,000 km of wastewater pipelines are installed in Norway.[263] Wastewater from 85% of the population is transported via these pipelines to 2,740 wastewater treatment plants with operational capacities of >50 population equivalents (Figure 45) prior to being discharged back into water basins.[264,265]

Norway's water distribution infrastructure, while extensive, is outdated. Approximately 30% of municipal water volume is lost through leaks and is therefore at risk of contamination from adjacent drainage pipelines, and repair rates are slow – at current rates it would take almost 150 years to adequately renovate the system.[266]


*Source: Miljødirektoratet, (2022)*

**Figure 45: Wastewater treatment facilities in Norway**

260 OECD. (2022). *OECD Environmental Performance Reviews: Norway 2022.* https://doi.org/10.1787/59e71c13-en
261 Miljødirektoratet (Norwegian Environment Agency). (2020). *Wetland Restoration Plan, Norway (2021 – 2025).* www.miljodirektoratet.no/sharepoint/downloaditem?id=01FM3LD2QC364EPMFHDFAIEQVSTLB3UZRM
262 Vannportalen. (2022). *Miljømål i vannforskriften.* www.vannportalen.no/miljomal/miljomal2
263 Statistisk sentralbyrå (Statistics Norway). (2022). *Municipal wastewater.* www.ssb.no/en/natur-og-miljo/vann-og-avlop/statistikk/utslipp-og-rensing-av-kommunalt-avlop
264 Statistisk sentralbyrå (Statistics Norway). (2022). *11641: Number of wastewater facilities and accompanying inhabitants, by region, compliance with treatment permits, contents and year.* www.ssb.no/en/statbank/table/11641/tableViewLayout1
265 Statistisk sentralbyrå (Statistics Norway). (2018). *Kommunale avløp 2017: Ressursinnsats, utslipp, rensing og slamdisponering 2017. Gebyrer 2018.* www.ssb.no/en/natur-og-miljo/artikler-og-publikasjoner/_attachment/370465?_ts=1675fa996e8
266 Steinberg, M. and Hyllestad, S. for the Norwegian Institute of Public Health. (2017). *Drinking water in Norway.* www.fhi.no/en/he/hin/infectious-diseases/drinking-water-in-Norway/?term=

## Annex 4: Additional information on biomass waste feedstock availability

In 2019, Carbon Limits estimated potential waste biomass feedstock amounts in 2030 by first estimating existing raw material volumes and then extrapolating the values using relevant growth factors or targets from various organizations. This analysis excludes feedstock amounts that are currently used for food or feed. The analysis also accounts for a 50% reduction in food waste by 2030 per the targets set by Bransjeavtalen, an agreement signed in 2017 between the Norwegian government and food industry to reduce food waste in the country.[267]

Another important paper assessing the potential of biomass in Norway is the recent paper by SINTEF, presenting BioCCS potential in Norway. Using a bottom-up approach and assessing the bio-feedstock quantities used in energy and non-energy applications, the paper maps biomass availability in the country. It presents the overall biomass availability in 2020 and projects it until 2030 under different scenarios. The most important aspect considered are "other" biomass quantities that could technically be used for bioenergy production but are currently unutilized or utilized in a way deemed sub-optimal. For example, fractions of agricultural wastes can be used for soil improvement, however, excess quantities could be integrated with BioCCS. SINTEF does take into consideration the biomass that is already used for non-energy use and presents the share of this feedstock that could be available for BioCCS. This estimate can be used as the "excess potential" of biomass in Norway. As seen in Table 6, the potential estimated in the paper is very high. Several aspects such as political conditions enabling this level of feedstock collection, accessibility of these feedstocks and the economic viability of the collection process must be considered to estimate a realistic potential. While the potential to achieve this scale by 2030 will be challenging, the estimates provide a reasonable target for achieving it by 2040 – 2050.

SINTEF uses a bottom-up approach to estimate the bio-feedstock availability from different sectors in Norway. The type and quantity of biomasses currently (2020 being used as a baseline year) being produced in different applications (agriculture, forest, aquaculture, ocean, food waste, etc.), including residues, waste and by-products, were mapped. These include (1) feedstocks currently used in energy applications are considered to be compatible with Bio-CCS; (2) feedstock quantities converted to non-energy products (e.g., paper, building materials, feed) are not deemed compatible with Bio-CCS; and (3) other biomass quantities that could technically be used for bioenergy production but are currently unutilized or utilized.

Following the total feedstock estimation, on a category basis, SINTEF estimates what percentage of this feedstock could be suitable for Bio-CCS applications. For example, livestock manure is currently mainly spread on fields as a soil enhancer. However, only limited quantities can be spread for both regulatory and logistical reasons, offering some opportunities for integration with Bio-CCS, this is estimated to be approximately 42% of the total feedstock. Similarly, a large share of straw is left in the field for soil enhancement as it is rich in nutrients (minerals, nitrogen, alkalis), resulting in a limited carbon potential for integration with Bio-CCS (around 26%). In the case of forestry biomass, in addition to timber, branches and tops, which are currently left in the forest mainly for economic and ecological reasons, could be integrated with Bio-CCS to a large extent. It is estimated that harvesting of forestry biomass could be increased by up to approximately 50% compared to today's level without any reduction in forest standing volume.

**For the projections to 2030, 3 scenarios were used:**

- "Business as usual" (BAU) scenario: 2020 situation is updated assuming annual increase/decrease using historical statistical data and unchanged state of-play concerning biomass uses;
- "Expansion" scenario: in addition to the "BAU" scenario, includes 1) the forest is harvested to its balance quantum, 2) seaweed production takes off 3) combustible waste fractions currently exported to Sweden are assumed to be treated (i.e. incinerated with energy recovery) in Norway
- "BioCCS-driven expansion" scenario: where the aforementioned events take place but are solely motivated by BioCCS, where all the additional biomass from the harvesting of the forest is integrated with BioCCS.

267 Landbruksdirektoratet (Norwegian Directorate of Agriculture). (n.d.). *Matsvinn.* www.landbruksdirektoratet.no/nb/jordbruk/miljo-og-klima/matsvinn

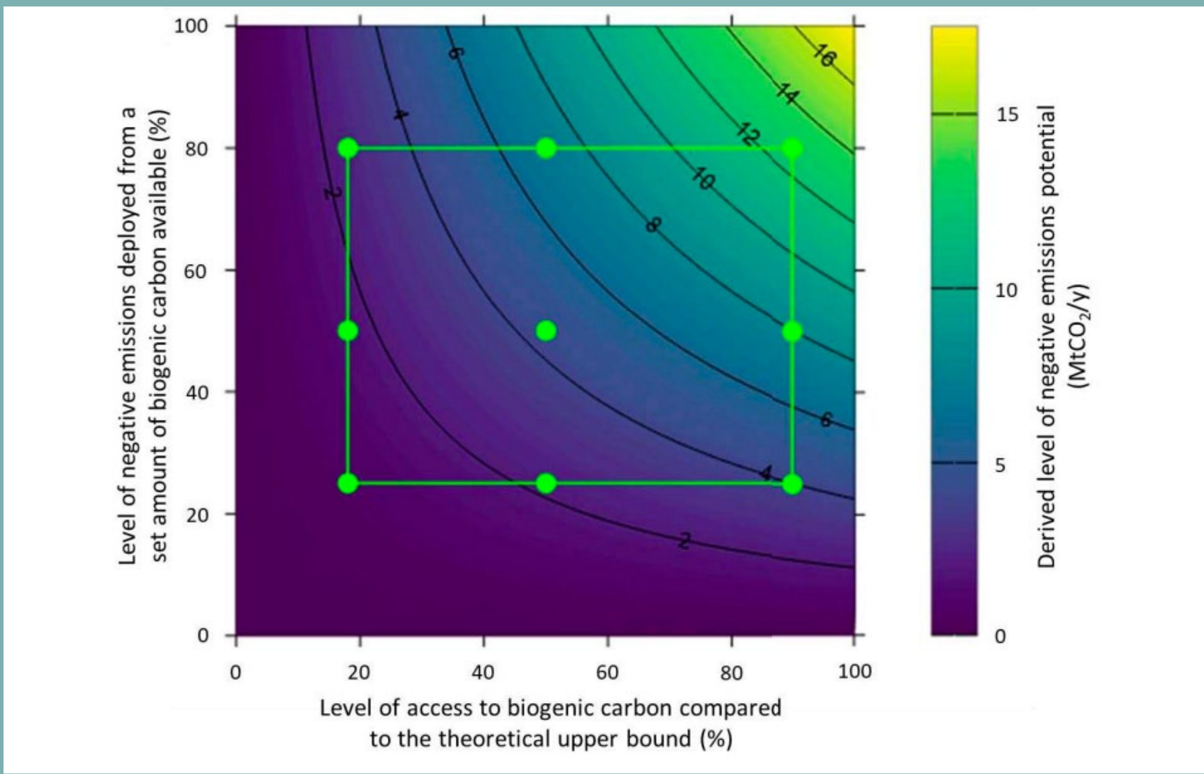
Using the estimated bio-feedstock availabilities and negative emissions, SINTEF uses two categories impacting the realization of this maximum potential: 1) the level of access to biogenic carbon compared to the theoretical upper bound (X-axis) and 2) the level of negative emissions deployed from a set amount of biogenic carbon available (Y-axis). Social acceptance of biomass use and challenges related to competition are considered in the first point, and political challenges are considered in the second point. 3 levels were considered for each category as defined below. The results of integrating available feedstock with the 2 categories is presented in Figure 46.

**Category 1:**

- 90% of the overall biogenic carbon is available, with very little competition for biomass
- 18% of the overall biogenic carbon is available, considering only low hanging fruits, i.e. biomasses already integrated with bioenergy production,
- 50% of the overall biogenic carbon to represent an intermediary case.

**Category 2:**

- 80% corresponding to technical, economic, and policy framework very favourable
- 2) 25% corresponding to a framework with limited incentives for BioCCS,
- 3) an intermediary framework resulting in a 50% on negative emission deployment.




*Source: SINTEF, 2023*

**Figure 46: Derived negative emission potential in function of (1) the level of access to biogenic carbon and (2) the level of negative emissions deployed from a set amount of biogenic carbon available**

**Box 4: Summary of methodology applied in SINTEF paper**

## Annex 5: Citizen panel engagement in Norway

The information in this Annex is taken from the citizen panel engagement report developed by NBT. Key insights relevant for this report are presented. All credits to NBT for the information presented in Annex 5.[268]

During the group discussions the participants were asked the following questions:

- What are the participants primary or general opinions on CDR technologies?
- What are the participant's attitudes towards these technologies when they are linked with concrete purposes, consequences, and risks?
- Do participants value different (ethical) considerations in relation to each other?
- Are there other considerations that are more important to participants than those discussed?

Below is the **summary of the main outcomes of these discussions**.

- Most participants were positive towards various CDR technologies. However, several participants found CDR technologies complex and had limited knowledge about them, while a few participants were uninterested, doubting human influence on climate change. Participants noted that none of the CDR technologies seem 100% preferable or absolutely concerning.

- Some concerns were expressed about CDR technologies readiness and adequacy of knowledge for implementation decisions. It was also highlighted that cost information, including energy cost per ton of $CO_2$ removed in Norway, is essential to make such decisions. Pilot projects and research are needed to better understand pros, cons, and consequences of various CDR pathways.

- Some participants raised concerns about competition for land use, energy use, and capital investments, when implementing various CDR pathways. At the same time, several participants argued for substantial investment in CDR technologies given the climate crisis and Norway's strong economy.

- Ocean-related CDR pathways, such as ocean fertilization and increased ocean alkalinity, were seen by some participants as highly uncertain with potential unknown consequences. At the same time, the potential of these CDR pathways was acknowledged, but risks of irreversible changes were noted.

- "Win-win" technologies that reduce emissions and produce energy were favoured. BECCS was highlighted as one of such technologies, having potential due to Norway's access to biomass and geological storage capacity.
- Biochar combined with tree planting was another favoured option. However, some concerns were raised about land use impacts of BECCS and biochar solutions.

- Natural-based solutions such as tree planting were generally considered as relevant pathways for Norway, due to country's suitable land. However, the potential for afforestation and reforestation in Norway was seen as limited. Some participants also raised concerns about the impact of poor forestry practices and non-native species on biodiversity.

- Wetland restoration was particularly favoured by the participants for its multiple benefits and technology readiness.

- Industrial-based solutions such as DACCS were seen as less invasive but energy and water intensive. Combining DACCS with renewable energy sources like solar and wind was discussed and the competitive advantage for geological $CO_2$ storage using existing oil and gas infrastructure was noted.

- Several participants emphasized the importance of measuring the impact of CDR technologies and ensuring that land use is sustainable and suitable for CDR.

268 For the participant profiles and detailed results from the citizen panel engagement, please contact Carbon Gap.

- It was also pointed out that Norway has "moral" responsibility as an oil-producing and wealthy country to develop CDR technologies. Carbon removal must be part of broader societal changes, including consumption and transportation. Several participants pointed out that government spending on CDR is necessary despite high costs. Moreover, some participants highlighted Norway's potential to finance and develop CDR technologies for global implementation.

- Participants highlighted that collaboration between government, society, and individuals is necessary for successful implementation of CDR.

## Disclaimer

This document was developed to present a background on Norway's potential for the deployment of Carbon Dioxide Removal (CDR) technologies. Considering most technologies presented in this report are still at initial phases of development, the assessment only provides high-level estimated potential. As methodologies applied in the report are based on theoretical estimates, it can be expected that several challenges have been overlooked or presented as future work at this stage. Further research and analysis using pilot projects are required in Norway to understand the realistic potential and impacts of CDR deployment in the country. The Background Report is expected to be used as a reading material for policy makers and stakeholders involved in CDR development in Norway.

Carbon Limits AS and Perspectives Climate Research gGmbH accept no liability as a result of this report and its contents being used, including any action or decision taken as a result of such use.

## Credits

This report was prepared by **Carbon Limits AS** and **Perspectives Climate Research gGmbH** for **Carbon Gap**

**Project leader: Irina Ålund** (Carbon Limits)

**QA: Gaëlle Cauchois** (Carbon Limits)

**Project members (Carbon Limits): Malavika Venugopal** (Task Lead),
**Anastasia Isaenko**, **Irina Semykina**, **Lauren Selleck**, **Marton Volstad**, **Valentin Gentile**

**Project Members (Perspectives Climate Research): Malte Winkler** (PM),
**Matthias Honegger** (QC), **Olivia Wallis**, **Matthias Poralla**, **Paulien Veen**

# About Us

## Carbon Gap

Carbon Gap was created to be Europe's first philanthropically funded environmental advocacy organisation focused exclusively on Carbon Dioxide Removal (CDR). The mission is simple: do whatever it takes to ensure that Europe becomes a leader in developing and deploying CDR solutions at scale in a safe and equitable manner to preserve a stable climate. Carbon Gap coordinated the delivery of the project that produced this report.

**www.carbongap.org**

## Carbon Limits AS

Carbon Limits works with public authorities, private companies, finance institutions and non-governmental organizations to reduce greenhouse gas emissions from a range of sectors. Our team supports clients in the identification, development, and financing of projects that mitigate climate change and generate economic value, in addition to providing advice on the design and implementation of climate and energy policies and regulations. Carbon Limits is a consultancy based in Oslo, Norway.

**www.carbonlimits.no**

## Perspectives Climate Research gGmbH

Perspectives Climate Research gGmbH ("Perspectives") is supporting both private sector companies and the public sector in several topics related to climate change mitigation. Perspectives is internationally recognized for its innovative, high-quality outputs in many fields of international climate policy. Resulting from more than two decades of world-wide research and consultancy experience on various topics, the company can offer deep insights and profound political and economic knowledge in a very flexible, client-oriented manner.

**https://perspectives.cc**