EXPERT OPINION

Case no: 24-036810ASD-BORG/02
Date: 22/06-2024
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Assessment of climate consequences from emissions from Breidablikk, Tyrving and Yggdrasil

0. Introduction

a) Background: The law firm Simonsen Vogt Wiig has asked me to provide an expert opinion on the climate impact of emissions from the Tyrving, Breidablikk and Yggdrasil petroleum fields, in connection with a dispute between Natur og Ungdom (Nature and Youth) and Greenpeace and the Norwegian state, represented by the Ministry of Petroleum and Energy, regarding the validity of three decisions on plans for the development and operation of these petroleum deposits.

b) Mandate: I have been requested to respond to the following mandate:
   1) Can you summarise climate science of relevance to your assessment?
   2) What are the climate consequences of 12, 87 and 365 MtCO2e for linear and non-linear climate change?
   3) What is the world's remaining carbon budget to limit warming to 1.5 degrees and two degrees with a 67 percent probability?
   4) How large are the emissions of 12, 87 and 365 MtCO2e compared to Norway's remaining share (calculated per capita) of the world's remaining carbon budget to limit warming to 1.5 and two degrees with a 67 percent probability?
   5) Can you describe some observed climate impacts in Norway?
   6) Could emissions of 12, 87 and 365 MtCO2e have an impact on climate change in Norway and contribute to harm?

c) Qualifications:

1990-1994 Dr. Scient. (corresponding to PhD) in climate modelling 1990-1994 (Nansen Environmental and Remote Sensing Center and University of Bergen)

1994-1996 Post. Doc. in climate modelling (Nansen Environmental and Remote Sensing Center and Stockholm University)

1996-2008 Head of the climate modelling group at the Nansen Environmental and Remote Sensing Center

1997- 2007 One of two initiators for the establishment of the *Bergen Climate Model,* one of four global climate models in Europe contributing to the fourth main report to the UN's Climate Panel (IPCC) in 2007

2001- 2014 One of three initiators for establishing the Bjerknes Centre for Climate Research, and member for the leader group of the Bjerknes Centre

2003-2008 Co-leader of the *Nansen-Zhu International Research Centre*, in Beijing, China

2005- 2008 Coordinator of the research project *DYNAMITE:* «Understanding the Dynamics of the Coupled Climate System», funded by the EU (9 partner institutions, budget EURO 3.0 million)

2007 Contributor to the fourth main IPCC report (IPCC AR4)

2007- 2011 Coordinator of the climate science project *NorClim* (nationally coordinated research project, budget NOK 26 million, 8 partners), funded by the Research Council of Norway

2008- Professor in oceanography at the Geophysical Institute, University of Bergen

2008- 2014 Co-leader of the CLIVAR *Working Group for Ocean Model Development*, which is an international research group that brings together the World's leading communities working with ocean modelling

2009 Recipient of the University of Bergen's *Melzer prize for outstanding science outreach*

2011- 2013 Coordinator of the climate science project *EarthClim* (largest nationally coordinated research project, budget NOK 26 million, 8 partners), funded by the Research Council of Norway

2014- 2017 Working group leader for the research project *EVA* (largest nationally coordinated research project, bubudget NOK 50 million, 8 partners), funded by the Research Council of Norway

2018 Recipient of *Olav Thon stiftelsens* prize for outstanding teaching

2018-2021 Co-leader for working package in the EU-funded research project *APPLICATE* («Advanced Prediction in Polar regions and beyond: modelling, observing system design and LInkages associated with a Changing Arctic climate»; budget EURO 8 million)

Co-author of 80 publications in international peer-reviewed journals, a total of 6788 citations from articles in peer-reviewed journals, and an *h*-index of 40.

Complete publication overview (with links) is available online. Some relevant publications:

He, S. P., **H. Drange**, T. Furevik, H. J. Wang, K. Fan, L. S. Graff, and Y. J. Orsolini, 2024: Relative impacts of sea ice loss and atmospheric internal variability on the winter Arctic to East Asian surface air temperature based on large-ensemble simulations with NorESM2. *Adv. Atmos. Sci.*, https://doi.org/10.1007/s00376-023-3006-9.

L.H. Smedsrud, A. Brakstad, E. Madonna, M. Muilwijk, S. K. Lauvset, C. Spensberger, A. Born, T. Eldevik, **H. Drange**, E. Jeansson, C. Li, A. Olsen, Ø. Skagseth, D. A. Slater, F. Straneo, K. Våge & M. Årthun. Nordic Seas Heat Loss, Atlantic Inflow, and Arctic Sea Ice cover over the last century Reviews of Geophysics (2022), 59, e2020RG000725, doi: 10.1029/2020RG000725

Muilwijk, M., Smedsrud, L.H., Ilicak, M., **Drange, H.**(2018), Atlantic Water heat transport variability in the 20th century Arctic Ocean from a global ocean model and observations, *Geophys. Res. Oceans*, https://doi.org/10.1029/2018JC014327

Årthun, M., Eldevik, T., Viste, E., **Drange, H.**, Furevik, T., Johnson, H. L., and Keenlyside, N. S. (2017), Skillful prediction of northern climate provided by the ocean, *Nature Comm.*, doi:10.1038/ncomms15875

Fløttum, K., **Drange, H**. 2017. The Paris COP21 agreement – obligations for 195 countries. In: Fløttum, K. (Ed.) *The role of language in the climate change debate*. New York/London: Routledge, 130-148.

Richter, K., R. E. M. Riva, and **H. Drange** (2013): Impact of self-attraction and loading effects induced by shelf mass loading on projected regional sea level rise, *Geophys. Res. Lett.*, DOI: 10.1002/grl.50265

Richter, K., J. E. Ø. Nilsen, and **H. Drange** (2012): Contributions to sea level variability along the Norwegian coast for 1960-2010, *J. Geophys. Res.*, 117, C05038, doi:10.1029/2011JC007826

d. Independence: I have no financial interest in the outcome of the case. The statement has been written in its entirety by me, without collaboration/interference/dialogue with other expert witnesses in the case.

1. Can you summarise climate science of relevance to your assessment?

1.1 Key points

- All man-made greenhouse gas emissions have an influence on global and local climate.
- CO_2 is the most important of the man-made greenhouse gases; around 20 percent of today's CO_2 emissions will affect the Earth's climate for 1,000 years or more
- For the first time, there are now sufficient observations, basic knowledge and good enough models to establish that weather events such as heatwaves, extreme precipitation, prolonged droughts and storm surges are directly influenced by man-made greenhouse gas emissions.
- A global warming of 1.5°C, 2°C or more will make a large difference to nature and society. The likelihood of passing tipping points - i.e. rapid, irreversible changes in climate - increases with increasing greenhouse gas emissions.
- The maximum emissions from Breidablikk, Tyrving and Yggdrasil - even if all other emissions from Norway were to be zero from 2023 - would mean that Norway exceeds emissions that are in line with the 1.5°C target.
- For the 2°C target, the maximum emissions from Breidablikk, Tyrving and Yggdrasil will correspond to around one third of the sum of all other future greenhouse gas emissions from Norway (within the 2°C target).
- Yggdrasil's warming contribution to the Earth's climate is equivalent to 180 times Norway's total annual energy production. Similarly, Breidablikk will warm the Earth's system by a factor of 43 times Norway's total annual energy production.
- Of the seven identified tipping points that may be triggered when global warming increases from 1.5 to 2°C degrees, five will affect Norway directly. These are the collapse of the ice cap in West Antarctica (resulting in higher sea levels), thawing of permafrost (resulting in unstable land/mountain slopes in the mountains and north in Norway, and which may contribute to increased methane emissions); absence of sea ice in the Barents Sea (which will affect marine life, marine transport and access to resources); reduced vertical mixing in the Labrador Sea (which in isolation will weaken the Gulf Stream system); and loss of glaciers (which will change landscapes and ecosystems, affect meltwater supply and tourism).

1.2 Briefly about the state of scientific knowledge

Basic experimental and theoretical knowledge that water vapour and various gases in the atmosphere have a warming effect on the Earth's climate has been known since the early 1800s (endnote 1). The effect is a prerequisite for all life on earth. In fact, the earth's surface temperature is around 33°C higher than it would be without an atmosphere (endnote 2). A logical consequence of this is that an increased content of heat-trapping gases in the atmosphere will add an additional warming to the Earth's surface. Research is clear that this is precisely what is happening (endnote 3).

Well-established scientific knowledge about *man-made* global warming - of which carbon dioxide (CO_2) resulting from the combustion of coal, oil and gas is the single most important contributor - is far from new. Examples include a report to the President of the United States in 1965, which concluded that continued CO_2 emissions from coal, oil and gas would

> *"almost certainly cause significant changes in the temperature..."*

and

> *"...could be deleterious from the point of view of human beings"* (endnote 4).

The 2021 Nobel Prize in Physics was awarded to Professors Syukuro Manabe (USA/Japan), Klaus Hasselmann (Germany) and Giorgio Parisi (Italy) for their contributions to the understanding of the Earth's climate system and other complex physical systems. Commenting on the award, Hasselmann stated that

> *"We've been warning against climate change for about 50 years or so"* (endnote 5),

while Parisi said that

> *"It's clear that for the future generations, we have to act now in a very fast way"* (endnote 6).

These statements are representative of the scientific status of man-made climate change (see also next section).

1.3 From the latest main report from the Intergovernmental Panel on Climate Change (IPCC)

The latest main report from the *Intergovernmental Panel on Climate Change* (IPCC) was published in the period 2021-2023 (endnote 7). This is the sixth assessment report from the IPCC, the previous assessment reports were published in 1990, 1995, 2001, 2007 and 2013/14. The IPCC's mandate is to inform governments about the state of knowledge concerning the Earth's climate. The IPCC does not carry out its own research, but reviews all relevant scientific literature in the field (endnote 8).

In the last assessment report, working group one, which reviewed all available literature on the physical climate system, gave the following key summary statement (endnote 9):

> "*It is unequivocal that human influence has warmed the atmosphere, ocean and land*"

and

> "*Human-induced climate change is already affecting many weather and climate extremes in every region across the globe. Evidence of observed changes in extremes such as heatwaves, heavy precipitation, droughts, and tropical cyclones, and, in particular, their attribution to human influence, has strengthened since AR5*"

(Comment: AR5 is the preceding main report of the Intergovernmental Panel on Climate Change, published in 2013/14).

The first of the above quotes states that it is scientifically certain that anthropogenic emissions from coal, oil and gas, as well as land use, have changed all parts of the Earth's climate.

The second quote is of particular importance: There are now sufficient observations, theoretical understanding and modelling to conclude that not only (average) climate, but also extreme weather events, are affected by anthropogenic greenhouse gas emissions. The fact that this conclusion is strengthened in the latest main report is not due to the fact that there has not been such a connection in the past, but that there is now sufficient knowledge to scientifically establish this on a global scale.

In addition, the latest main report concludes that any greenhouse gas emissions will exacerbate global warming (endnote 10):

> *"Every tonne of CO_2 emissions adds to global warming",*

and regarding the relationship between intensified global warming and extreme weather events (endnote 11):

> *"With every additional increment of global warming, changes in extremes continue to become larger.*

The last two quotes state that global greenhouse gas emissions must be reduced to (i) limit global warming and (ii) limit the frequency and magnitude of extreme weather events.

Changes in climate also have non-human, often called naturally occurring, causes. Factors such as variations in the Sun's radiation, the frequency and intensity of volcanic eruptions, and the redistribution of heat between the ocean surface and its abyss are factors belonging to the last group. In a new study, which is an annual update of the most important climate indicators reviewed in the IPCC reports, reaffirms the conclusion from the 2021 IPCC report that global warming over the past decade is almost entirely (almost 100 percent) man-made (endnote 12):

> "WGI AR6 found that, averaged for the 2010-2019 period, essentially all observed global surface temperature change was human-induced, with solar and volcanic drivers and internal climate variability making a negligible contribution. This conclusion remains the same for the 2014-2023 period. Generally, whatever methodology is used, on a global scale, the best estimate of the human-induced warming is (within small uncertainties) similar to the observed global surface temperature change."
>
> (Comment: WGI AR6 is the sixth (and final) main report of the Intergovernmental Panel on Climate Change, published in 2021)

1.4 Some examples of observed changes in climate

Some central global climate indicators are briefly presented in the following.

(1.4a) Global surface temperature

All available analyses of measured surface temperature show that 2023 is by far the warmest year since instrumental observations began around 1850

A compilation of the six most used analyses of annual mean, global temperature is shown in Figure *1*. Although there are minor differences between the time series, they show the same overall patterns, with the highest global temperature by far in 2023.

Averaged over the ten-year period 2014-2023, the global temperature has risen by approximately 1.2 ^{o}C since 1850-1900 (i.e. since measurements began, or the "pre-industrial" era). This warming is almost 100 percent man-made (endnote 12).

The single year 2023 is around 1.4 ^{o}C warmer than the period 1850-1900, of which around 1.3 ^{o}C is man-made (endnote 12). The difference between actual warming and the anthropogenic contribution of 0.1 ^{o}C is not fully explained, but is largely due to natural variations in the climate system.

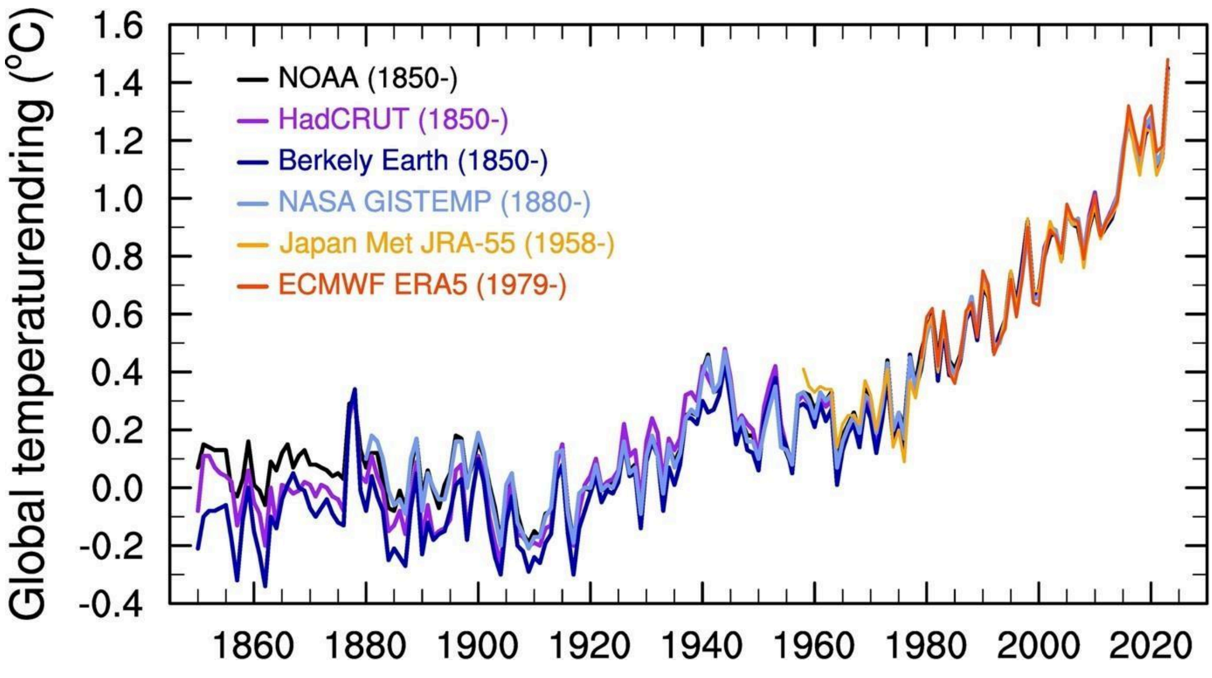


Figure 1: Change in the annual mean global surface temperature since 1860 from six different global temperature analyses; three from the USA (NOAA, Berkeley and NASA), two from Europe (HadCRUT and ECMWF) and one from Japan. The analyses starting in 1850 and 1880 are all based on observed surface temperature, while the analyses starting in 1958 and 1979 are based on numerical models that include observed temperature. The time series have the same average value for
the joint period 1981-2010, with a temperature 0.69 ^{o}C lower for the period 1850-1900 (0.69 ^{o}C is an estimate of the warming between the two periods based on the latest IPCC main report). Data available in endnote 13.

One method of quantifying the warming in 2023, without emphasising random year-to-year variations, is to look at the global temperature trend line for the last 30 years and compare it with pre-industrial temperatures. Global warming since pre-industrial times would then be around 1.3°C (endnote 14). Based on this, a global warming since pre-industrial times of 1.3°C is used in this explanation.

It is also likely that the current global temperature - if it continues at current levels (which is highly likely) - is higher than at any point in the last hundred thousand years, perhaps even further back in time (endnote 15).

For the record, the change in global temperature shown in Figure *1* has an estimated accuracy of around ±0.05°C after 1950, increasing to ±0.1°C a century ago (endnote 16). This means that changes greater than ±0.1°C are statistically certain. The global temperature increase since pre-industrial times is around 1.3°C, and is therefore far greater than the uncertainty in the measurements and their analysis. Measured changes in global temperature, as well as a number of other climate variables, are therefore statistically certain.

(1.4b) 1.5°C *target*

As Figure *1* illustrates, the single year 2023 is almost 1.5°C warmer than pre-industrial times, the latter defined as the average value for the period 1850-1880.

Since global air temperature (naturally) varies from year to year, it is not a given that the next few years will be as warm as 2023. Consequently, it is not a given that 1.5°C of warming has passed. However, it is only a matter of a few years, probably less than a decade, before global warming passes 1.5°C (endnote 12).

For the first time since temperature measurements began around 1850, *all* days in 2023 were more than one degree warmer than pre-industrial times. Furthermore, 173 days - which in practice means half of the days in 2023 - had temperatures more than 1.5 degrees above pre-industrial times (endnote 17).

It is also the case that *all of* the last 12 months show significant warming. This is illustrated in Figure *2*, which shows the change in global monthly temperature since 1990. It is also worth noting that for the period from September 2023 to April 2024, the global annual temperature has been 1.5 ^{o}C above the temperature for the period 1850-1900 ("pre-industrial" temperature). May 2024 has also been record warm compared to previous May months.

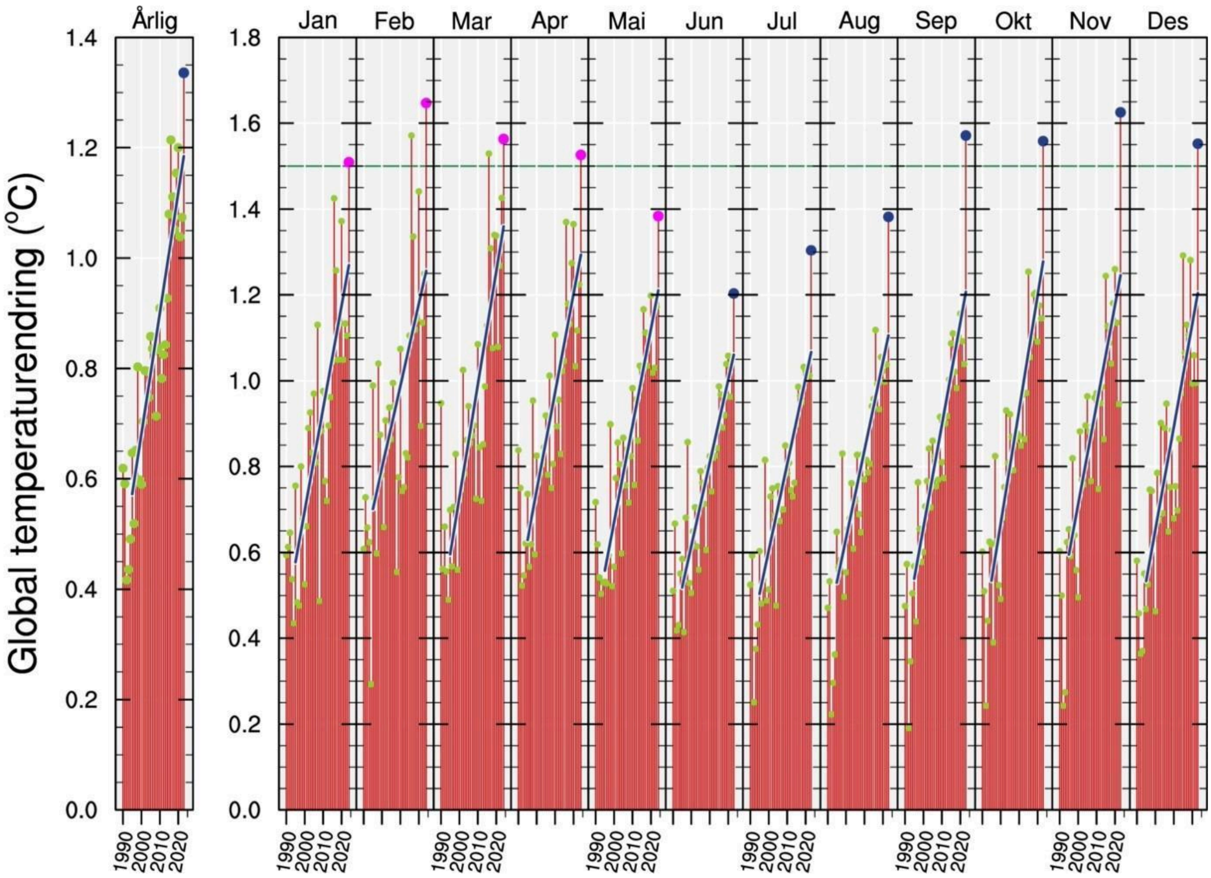


Figure 2. Annual global temperature change (in °C, left) and global temperature trend for individual months of the year, all since 1990. Temperature for the most recent year/month is highlighted with a large circle; deep blue colour shows temperature for 2023; magenta colour shows temperature for 2024; and straight lines show trend for the last 30 years. In addition, 1.5 °C warming relative to "pre-industrial" times is shown with a green dotted line. Zero value is the average value for the period 1850-1900. Data from the National Ocean and Atmosphere Administration (NOAA), USA, see endnote 18

(1.4c) Scientific importance of the 1.5°C target

From a scientific point of view, 1.5°C of warming is important as this is seen as a threshold value that could initiate various tipping points - which can be understood as irreversible changes in parts of the Earth's climate system. This is discussed in more detail later.

(1.4d) Global surface temperature in 2024

As shown in Figure *2*, global warming continues at a record high in 2024, with monthly anomalies at or above 1.5 °C for the months of January to April 2024, and with a record high May temperature.

Due to an ongoing transition between high and low ocean temperatures in the equatorial Pacific Ocean - a naturally occurring variation in the Earth's climate, known as El Niño and La Niña respectively - temperatures are not expected to be as high for the remaining months of 2024.

Despite falling ocean temperatures in the Pacific, it is at least 50 percent likely that 2024 will be the warmest year since pre-industrial times (endnote 19), continuing the trend of ever-increasing global temperatures.

(1.4e) Global ocean temperature

Figure *3* shows the development of absolute (actual) sea temperature since 1985. Between the period 1985-1989 and 2020-2024, global ocean temperatures have risen by around 0.7°C. There has been a particularly dramatic warming in sea surface temperatures from March 2023, with record high and hitherto unknown monthly temperatures since.

It is estimated that 90 per cent of global warming in 2023 is man-made (endnote 12), with increased greenhouse gas emissions and reduced particle emissions as the main causes. The rapidly increasing ocean temperature is affecting the atmosphere, resulting in e.g., more severe and longer-lasting extreme weather events.

The ocean warms not only at the surface, but also to great depths. The main heating is found in the top 700 metres of the water column, but there is also significant heating down to 2,000 metres depth, as well as the abyss (endnote 20). Warming of the world's oceans plays a key role for the Earth's climate, see next section.

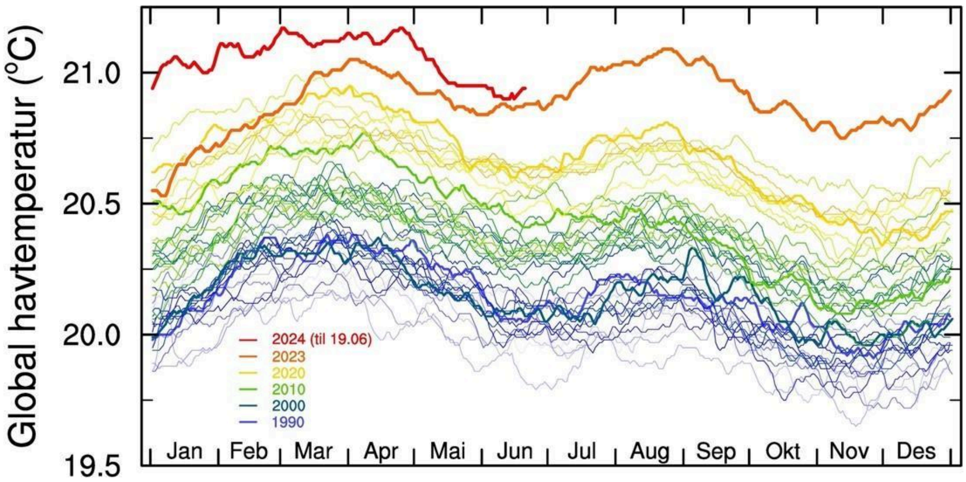


Figure 3: Daily global ocean temperature (°C) from 1981 to 19 June 2024 for the area 60° S to 60° N based on measurements from satellites, ships, buoys and drifters. Highlighted curves show temperature for the years 1990, 2000, 2010, 2020, 2023 and 2024. Data source in endnote 21

(1.4f) Ocean heat content/global ocean temperature

The single, most profound change in the Earth's climate is found in the ocean, in the form of increased ocean temperature. This is illustrated in Figure 4, displaying changes in the total *heat content*[1] of the atmosphere, ocean and land since 1960.

The figure shows that around 90 per cent of the increase in the Earth's heat content is caused by increased ocean temperature; nine per cent is due to the heating of solid Earth (soil and bedrock) and the melting of land and sea ice; while (only) one per cent is due to increased air temperature. The overall dominant role of the ocean is because water molecules can absorb and retain around 3,500 times more heat than air. Changes in the Earth's climate "health" are therefore - to a dominant degree - controlled by the ocean. The warming of the ocean is measured from the surface to the abyss (endnote 22).

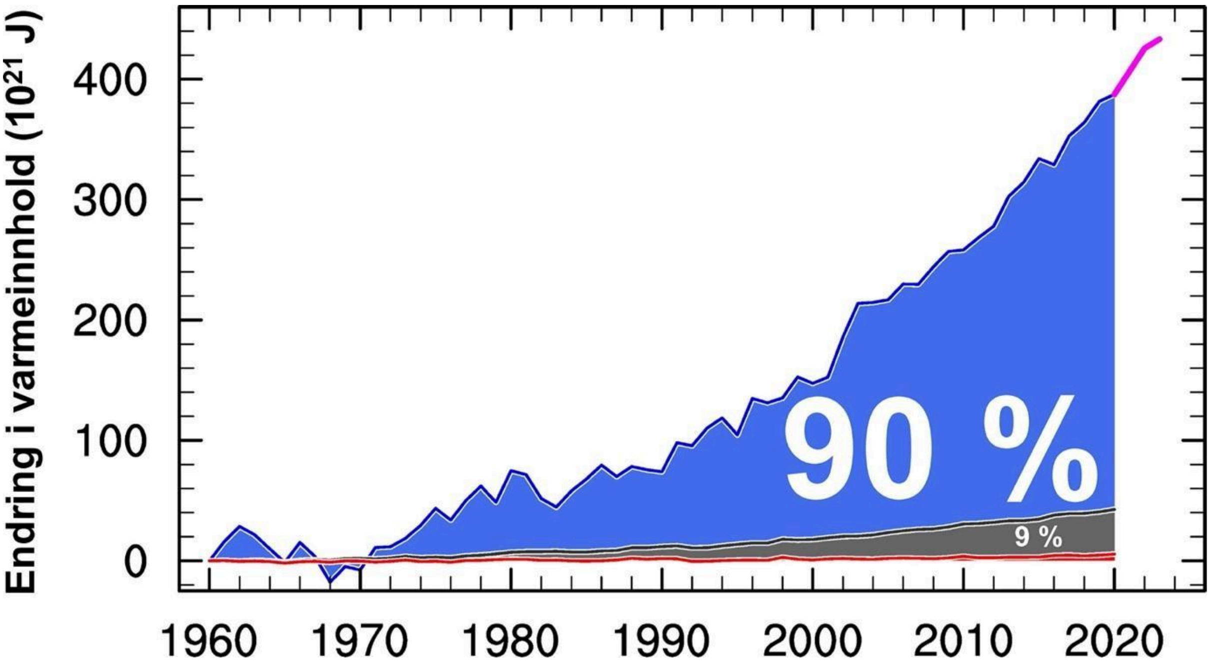


Figure 4. Measured change in the Earth's heat content (in 10^{21} Joules) from 1960. Red colour corresponds to increased heat in the atmosphere (due to increased air temperature); grey colour shows increased heat in bedrock (due to bedrock warming) and heat used to melt land and sea ice; and blue colour shows increased heat content in the ocean (due to ocean warming). The purple curve shows the change in ocean heat content for the years 2021-2023. Around 90 per cent of the warming of the Earth system is found as warmer oceans; nine per cent as warmer bedrock and due to melting ice; while (only) one per cent is due to warming of the atmosphere. Data source in endnote 23.

[1] Heat content is a measure of energy; for example, it takes around 3,500 times more energy to heat 1 kg of water by 1 °C compared to 1 kg of air. Consequently, a temperature increase of one degree in one cubic metre of seawater requires 3,500 more energy than heating one cubic metre of air by one degree.

(1.4g) Atmospheric CO_2 content

The atmospheric content of CO_2 reached a new record in 2023. Today's CO_2 content is higher than over the last one million years (and probably further back in time, possibly more than ten million years; endnote 24).

It is a scientifically established fact that the main cause of today's high CO_2 levels is the extraction of - in particular - coal, oil and gas. These CO_2 emissions started with the industrial revolution around 1750.

Figure *5* shows the development of atmospheric $CO_{(2)}$ content since 1850 (blue colour), together with the change in global temperature from the Hadley Centre in England (red line; this curve is identical to the "HadCRUT" time series in Figure *1*).

The increase in atmospheric CO_2 content is indisputable and rapid. There is also a clear connection between global air temperature and the air's CO_2 content, although there are other lines of evidence that prove that the ongoing warming is caused by an increased (man-made) greenhouse effect, of which CO_2 is the most important component (endnote 25).

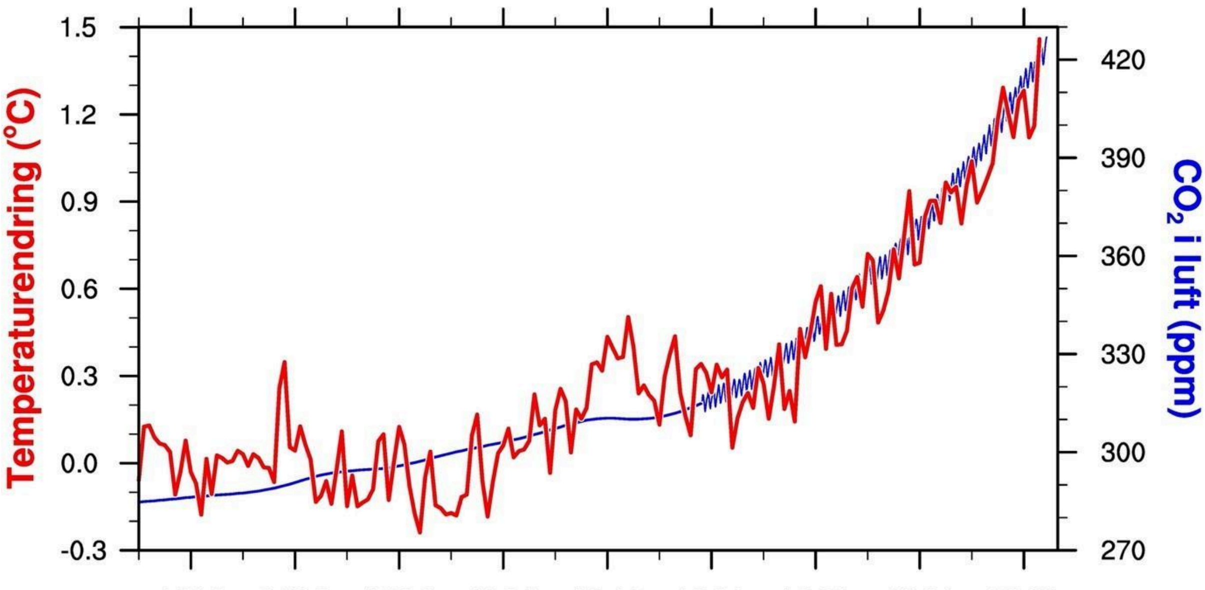


Figure 5. Comparison of CO_2 in air in blue colour (unit is ppm or "parts per million"; 400 ppm corresponds to 0.04 per cent CO_2 in air), and change in annual mean global temperature from the Hadley Centre in England (which is the same curve as the one labelled "HadCRUT" in Figure 1). The smooth CO_2 curve is based on analysis of air trapped in ice cores; the oscillating CO_2 curve is from Mauna Loa, Hawaii. Data sources in endnote 26.

(1.4h) Record high and accelerating sea level rise

Figure *6* shows the change in global sea level since 1900 based on sea gauge (or sea level) measurements from the year 1900, and from satellite measurements since 1993. The figure shows that global sea level has increased by more than 20 cm since 1900, and that the trend since 2010 corresponds to a global sea level rise of 45 cm in

100 years. Current sea level rise is partly due to warmer oceans, but increasingly due to melting ice caps in Greenland and Antarctica (endnote 27).

For humankind, global sea levels will remain high "forever", i.e. until the next ice age comes, some 50,000 to 100,000 years into the future (endnote 28). The possibility of future sea levels several metres higher than at present, with existential consequences for society, food production, access to fresh water, ecosystems, cultural heritage, etc., was one of the main arguments for the Paris Agreement's establishment of the 1.5-degree target (endnote 29).

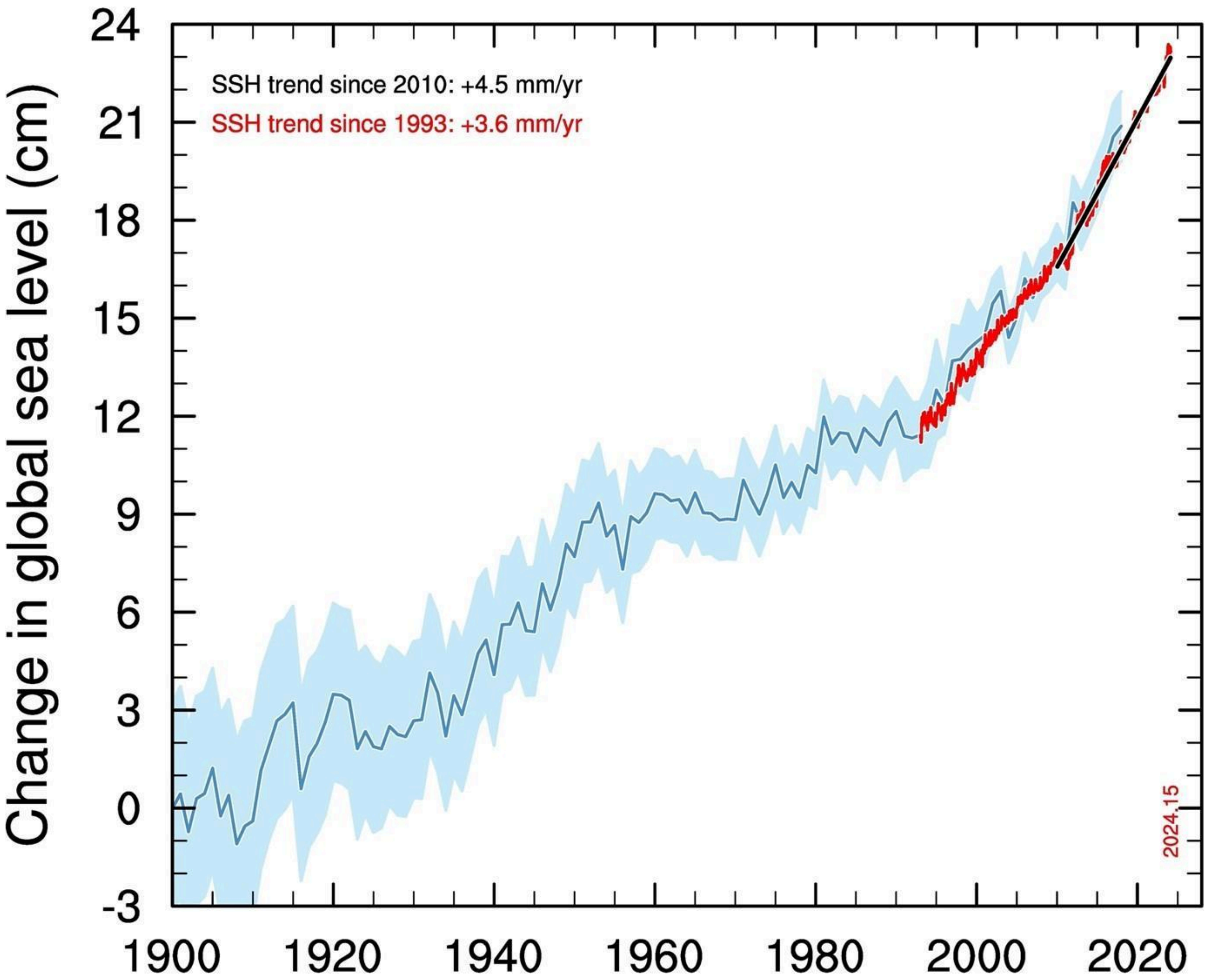


Figure 6. Change in global sea level (in cm) based on water level measurements along the coasts of the world's oceans (blue curve and shading), as well as from satellites (red colour, until 15 February 2024). The rise since 2010 is 4.5 mm/year, equivalent to 45 cm per 100 years should the current change continue. Data sources in endnote 30

(1.4i) Reduced ice extent and thickness of the Arctic sea ice

The extent of sea ice in the Arctic is rapidly diminishing because of global warming. In September, which is the time of the year with the least sea ice in the Arctic, around half of the ice has disappeared compared with the 1950s, see Figure *7*.

Parallel to the reduced extent of sea ice, the ice is both thinner and younger than the situation a few decades ago (endnote 31).

Without rapid and significant reductions in greenhouse gas emissions, it is expected that the September ice in the Arctic, i.e. the Arctic "summer ice", will more or less disappear by the middle of this century (endnote 32).

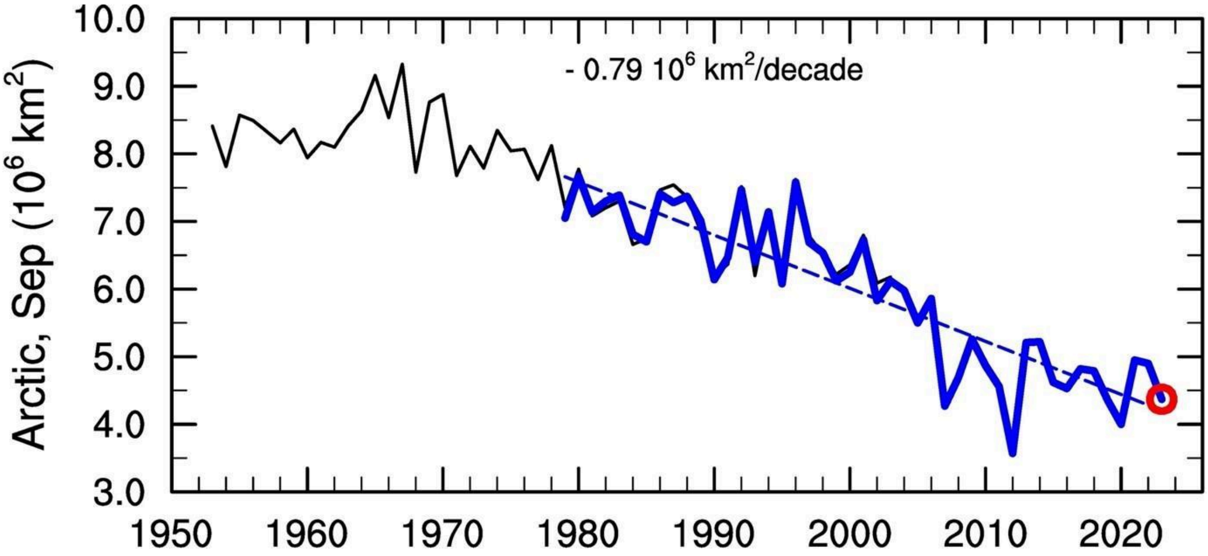


Figure 7. Observed extent (in million km^2) of sea ice in the Arctic for the month of September. Black curve is based on historical impairments; blue curve from satellite. September 2023 is shown with a red circle. Data sources in endnote 33

1.5 Changes in extreme weather events

Figure 8 from the latest IPCC main report summarises observation-based evidence for changes in extreme heat events, and the degree to which these changes can be attributed to human-induced greenhouse gas emissions. Similarly, Figure 9 from the IPCC displays observation-based evidence for changes in extreme precipitation, and the degree to which these changes can be attributed to human-induced greenhouse gas emissions.

For Northern Europe, presented as the “NEU” cell in Figures 8 and 9, there is now a demonstrable link between anthropogenic greenhouse gas emissions and extreme temperature events (Figure *8*). The same is true for extreme precipitation events (Figure *9*). This link is important since extreme weather events directly impact individuals, society and infrastructure, including individual and societal security, food production, water access, etc.

With record high temperatures, there were also a number of extreme weather events in 2023. Many of these events were exacerbated by human-induced warming, as shown by the World Weather Attribution (endnote 34). This includes prolonged droughts and severe heatwaves in North America, South and Central Europe and Asia, widespread wildfires in (especially) Canada and extreme precipitation on several continents. In many ways, the world is now in uncharted territory, weather-wise (endnote 35).

Norway also experienced several extreme weather events in 2023, with the extreme weather event "Hans" as the largest and most serious incident. According to Finance Norway, the

> "Weather and natural damage … is record high, with a cost of NOK 7.4 billion for damage to buildings and contents" (endnote 36).

In addition, “Hans” caused damage to municipal and state infrastructure and property. For the latter, the government has set aside a total of NOK 1.7 billion for municipal support to rebuild damaged infrastructure, etc., of which NOK 1 billion was allocated by the end of February 2024 (endnote 37).

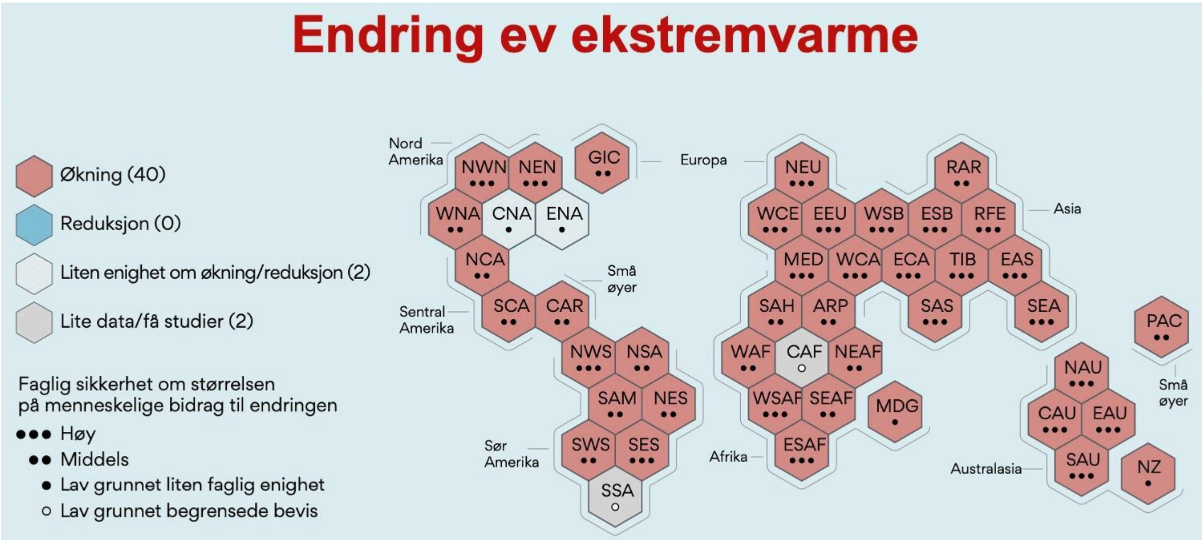


Figure 8. Graphical representation of changes in extreme heat on Earth. Each of the cells represents a geographical area, e.g. NEU is representative of Northern Europe. Red colour shows an increase in extreme heat events; three dots show that there is a high degree of certainty about the connection between extreme heat events and human contributions. Source, see endnote 38.

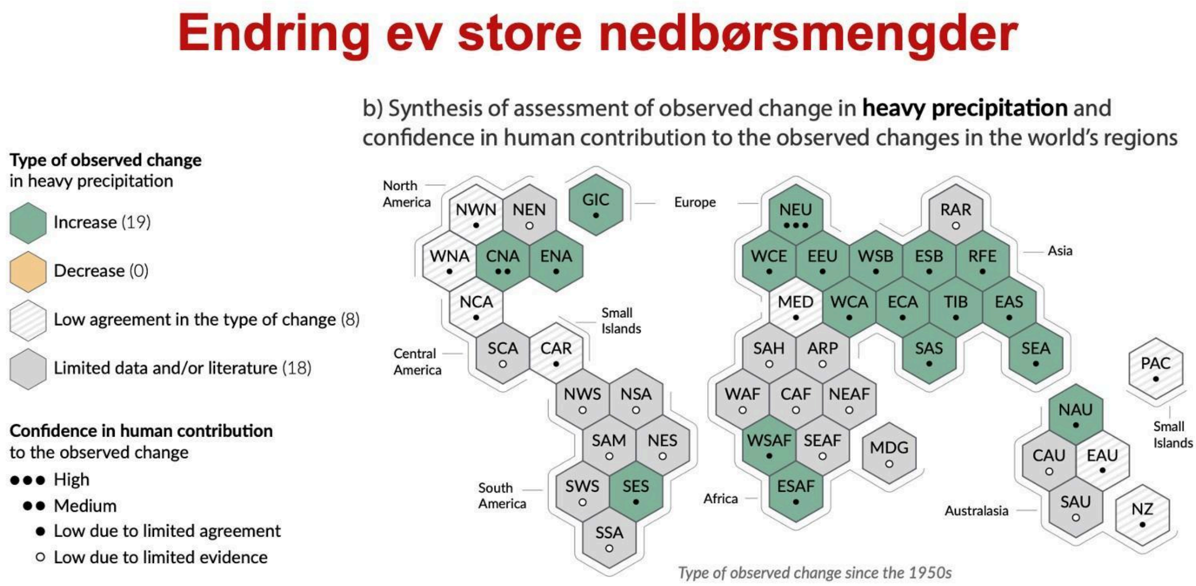


Figure 9. As Figure 8, but for extreme precipitation. For the Northern Europe area (NEU), there is a demonstrable increase in extreme precipitation events, and there is a high degree of certainty that this is linked to human contributions. Source, see endnote 39.

1.6 Tipping points

A major and real concern related to global warming is the possibility that one or more parts of the climate system may rapidly - and possibly permanently - change character (endnote 40). These events are also called non-linear changes in climate; they can be explained by the fact that a “last” push may cause a rapid change in e.g., weather or sea level. If so, a tipping point has been crossed. The change can be irreversible, implying a very long time for the system to (possibly) return to its starting point.

Examples of tipping elements are partial collapse of the ice caps in Greenland and Antarctica; that the sea ice in the Arctic disappears in summer; that areas of permafrost thaw; or that the boreal forest is dying in the south and moving poleward in the north.

An overview of the most central tipping points and their possible crossings is shown in Figure 10. It follows that seven tipping points crossings go from "possible" to "likely" when global warming increases from 1.5^{o}C to 2^{o}C. This illustrates the importance of limiting global temperature rise as much as possible.

Of the seven tipping points crossings that may occur as global warming increases from 1.5^{o}C to 2^{o}C, five will affect Norway directly. These are:

- collapse of the ice cap in West Antarctica (resulting in higher sea level),
- thawing of permafrost (leading to unstable land/mountain slopes, which can contribute to increased methane emissions),
- the absence of sea ice in the Barents Sea (which will affect marine life, marine transport and access to resources),

- reduced vertical mixing in the Labrador Sea (which in isolation will weaken the Gulf Stream system); and
- loss of glaciers (which will change landscapes and ecosystems, affect meltwater supply and tourism).

A sixth, geographically nearby tipping point that can be activated when global warming increases between 1.5°C and 2°C is rapid loss of the Greenland ice sheet, resulting in a higher global sea level. Melting of the Greenland ice sheet has, however, limited influence on the sea level along the Norwegian coast (endnote 41). The reason for this seemingly paradox is that the loss of ice on Greenland will change the Earth's centre of gravity field so that the subsequent sea level increase will be found far away from the source, in this case in the tropics and in the southern hemisphere. Correspondingly, the loss of ice in Antarctica will lead to the largest sea level rise in the northern hemisphere (including Norway) and in the tropics. Melting of the Greenland ice sheet may, however, affect Norway since more fresh (melt) water supplied to the North Atlantic may weaken the Gulf Stream system.

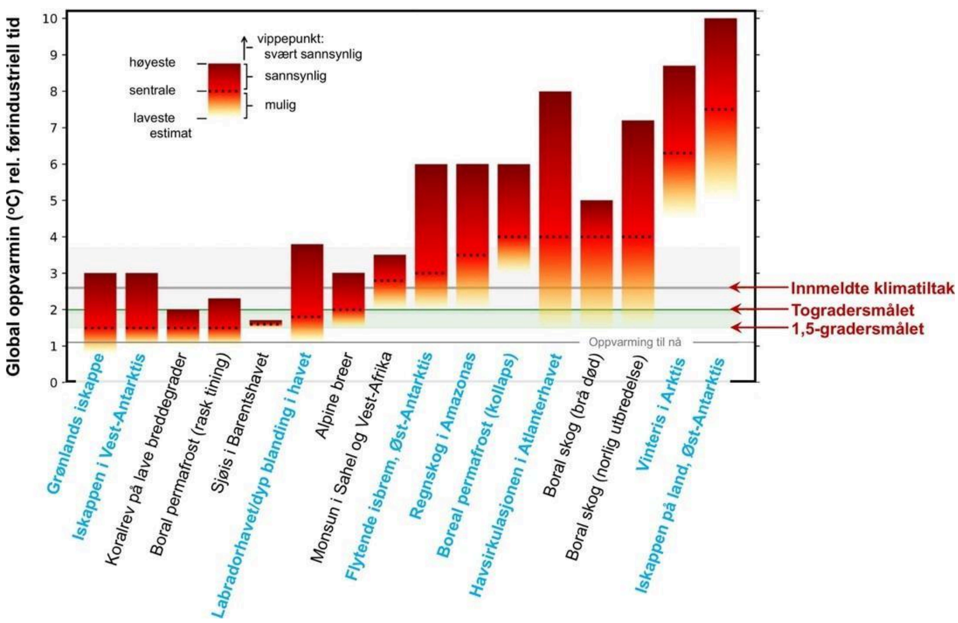


Figure 10. Illustration of nine tipping points that will affect global climate (blue font) and seven other tipping points with more localised effects (black font). The vertical bars show when the tipping points can be expected to materialise based on available knowledge; the black dotted line shows when the tipping points go from being possible to probable. Vertical scale shows change in global temperature (°C) since pre-industrial times, with the 1.5 and two-degree targets shown to the right. "Registered climate measures" indicates the most likely global temperature in the year 2100 if all countries fulfil their registered climate targets. Figure is based on figure 2 in endnote 42.

1.7 Examples of high impact-low likelihood changes in climate

Several weather and climate-related events have a high damage and economic/ecological impact, but a low likelihood of occurrence. Sea level rise is an example of this.

Rapid and large sea level rise can only occur with rapid melting or collapse of the Greenland and Antarctica ice caps. The reason for this is that the two ice caps hold so much water in the form of ice that if the Greenland ice sheet were to melt, global sea levels would rise by 7 metres, while melting of the Antarctic ice sheet would contribute 58 metres (no one believes that full melting will occur, but the figures indicate the significance for global sea levels). Today, both ice caps contribute to rising sea levels (endnote 43). Should these contributions increase with increased temperature, the global sea levels could rise by several metres, with serious consequences for individuals, societies, nations, food production, water access and quality, ecosystems, ecosystem services, etc.

The 2021-report from the IPCC illustrates large and rapid sea level rise projections due to the disintegration of the Greenland and Antarctic ice sheets with the red dashed line until 2100, and the two vertical columns for year 2300 (Figure *11*).

While a global sea level rise of between 50 and 80 cm is considered most likely towards the end of this century (endnote 44), large contributions from the Greenland and/or Antarctic ice sheets cannot be ruled out (the dashed lines in Figure *11*).

A recently published study concludes that global warming has already reached a level that increased melting from West Antarctica is inevitable in the next couple of decades, possibly with collapse of the West Antarctic ice sheet as a result (endnote 45). West Antarctica alone could contribute several, in the range 3-5, meters of global sea level rise.

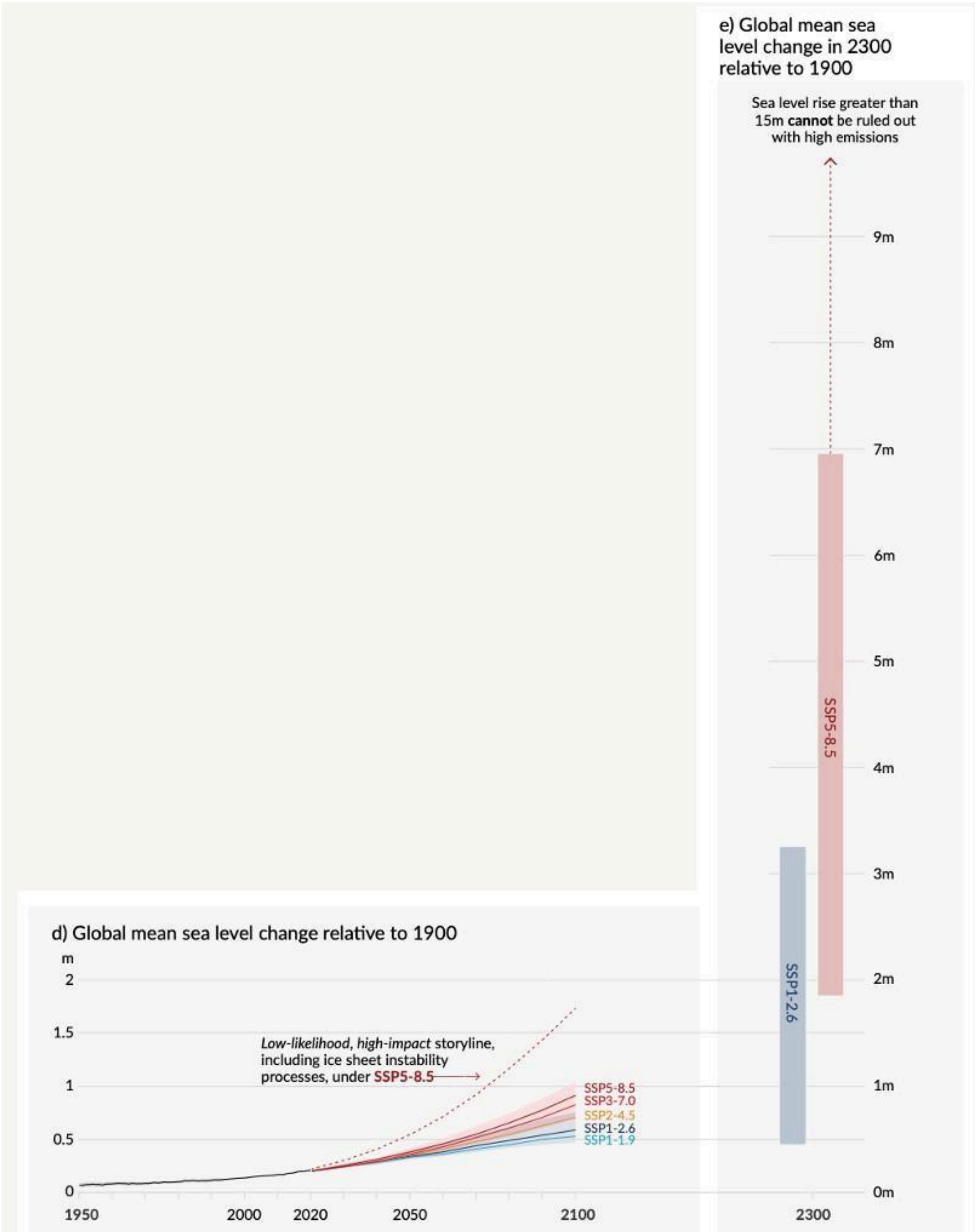


Figure 11. Change in global sea level between 1950 and 2300. The left-hand side of the figure (marked d) shows modelled sea levels from 2020 to 2100 based on five different emission scenarios; scenario SSP1-1.9 is in line with the 1.5 degree target, while scenario SSP58.5 is a business-as-usual scenario (i.e. without reduced greenhouse gas emissions). In addition, a possible rise in sea level with a large and abrupt loss of ice from the ice caps is projected. All relative to sea level in 1900. The right-hand side of the figure indicates sea level change in the year 2300 for the two-degree target (blue colour) and the business-as-usual scenario (red colour). Note that both scenarios involve a sea level rise of several metres. Figure from endnote 46

The Norwegian coast will also be affected by the melting of the ice caps, mainly from Antarctica, and to a significantly lesser extent from Greenland (due to the associated weakening of the gravitational pull from the Greenland ice cap as mentioned above). The coast of southern and western Norway will experience the largest sea level rise, since the land uplift is smallest here. Only rapid reductions of greenhouse gas emissions can delay - and possibly prevent - significant contributions from the ice caps to global and local (as for the Norwegian coast) sea levels.

In a recently published report on possible sea level rise projections along the Norwegian coast (endnote 47), the possibility of rapid sea level rise is described as follows:

> "For a low-probability but high-consequence scenario in which very high emissions (SSP5-8.5) are combined with rapid ice loss in Antarctica, the average relative sea level rise in Norway could approach between 1 and 1.5 metres by 2100. In some places along the coast, particularly Stavanger and Bergen, sea level rise could approach 2 metres...".
>
> (Comment: "SSP5-8.5" is an emissions scenario with continued high greenhouse gas emissions this century. "Relative sea level rise" is sea level rise as seen from land, i.e. when land uplift is taken into account).

1.8 Multiple reasons for the important role of CO_2 in changes in climate

The climate impact of man-made CO_2 emissions is particularly important for four reasons:

(1.8a) Heating

Firstly, increasing CO_2 content in the atmosphere leads to reduced heat loss from the Earth to space, which means higher temperatures on Earth - both in the atmosphere, in the oceans and on land - and with it a changing climate. As mentioned above, this connection has been known for more than a hundred years (endnote 48), and it has overwhelming support in the scientific literature, in scientific organisations and in academia worldwide (endnote 49).

(1.8b) Main contribution to man-made warming

Secondly, very large amounts of CO_2 are added to the atmosphere. We must go back two to three million years in time – i.e. long before the existence of modern humans on Earth – to find an atmosphere with corresponding levels of CO_2 (endnote 50). At that time, the high CO_2 level resulted from warming due to a shorter distance between the Sun and the Earth, and with subsequent release of CO_2 from the sea. This contrasts with the current situation, which is due to man-made greenhouse gas emissions. In total, man-made CO_2 emissions account for around two thirds of man-made global warming (endnote 51).

(1.8c) Longevity

Thirdly, around 20 percent of today's CO_2 emissions will affect the Earth's climate for a thousand years or more (endnote 52), corresponding to more than 30 human generations. Each day of continued extraction of coal, oil and gas will consequently cause future generations increasingly greater climate challenges. Only rapidly reduced CO_2 emissions will reduce the possibility of widespread and long-lasting climate change. Alternatively, CO_2 must be captured from the atmosphere at a rate greater than anthropogenic CO_2 emissions, followed by safe and long-term storage on Earth, e.g. in geological formations. CO_2 absorption from air is discussed, but there are no solutions as of today (or in the near future) that can sufficiently mitigate - less balance - man-made CO_2 emissions (endnote 53).

(1.8d) Ocean acidification

Fourthly, since CO_2 is solvable in water, the ocean absorbs around a quarter of today's CO_2 emissions (endnote 54). The ocean's absorption of CO_2 causes the ocean's pH value (acidity) to drop, which is often referred to as ocean acidification. Ocean acidification due to the extraction of coal, oil and gas is measurable throughout the World's oceans (endnote 55).

The consequences of ongoing and future ocean acidification are poorly known, but calcareous shell-forming organisms such as many plankton species, crustaceans, crabs and corals will gradually have increasing difficulties forming shells (endnote 55). Furthermore, corals and calcareous shells and sediments will gradually disintegrate. There is also reason to expect that fish eggs and larvae will be affected by reduced pH values (endnote 55). Ocean waters with low water temperatures, such as in the Norwegian and Barents Sea, are more susceptible to acidification than areas with higher water temperatures.

If CO_2 emissions continue at today’s levels, we may get a stronger acidification of the World's oceans than has been the case during the last 24 million years (endnote 56), with unknown consequences for marine life. Only significant cuts in CO_2 emissions - for example, in line with the 1.5 degree target - will change this (endnote 57).

2. What is the significance of 12, 87 and 365 MtCO2e from Tyrving, Breidablikk and Yggdrasil for linear and non-linear climate change?

2.1 Linear relationship

A particularly central and well-established result of climate research, at least since the IPCC's Fifth Assessment Report in 2013/14, is that there is a close linear - or a close one-to-one - relationship between cumulative CO_2 emissions since the start of the industrial revolution and global warming. This relationship makes it possible to connect a given amount of CO_2 emissions to a (probable) future global temperature. Figure *12* illustrates the close to linear relationship between cumulative CO_2 emissions and global warming.

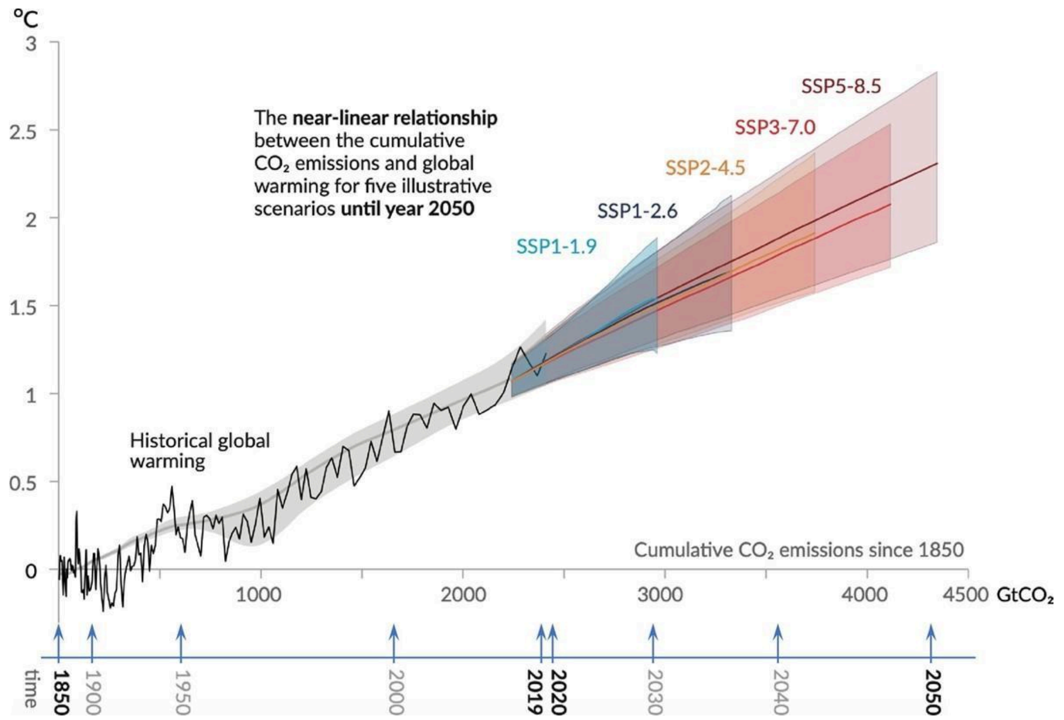


Figure 12. Relationship between the sum of global CO2 emissions since 1850 (billion tonnes of CO_2; top horizontal axis) versus the change in global temperature since 1850-1900 (°C; vertical axis). In addition, the timing of the cumulative CO2 emissions is shown on the bottom horizontal axis. The black curve shows historic correlation between CO_2 emissions and changes in global temperature for the period 1850-2019; the colour shading shows the corresponding relationship for different emission scenarios. Figure from endnote 58.

The relationship described above and illustrated in Figure *12* means that every tonne of CO_2 - regardless of where or when the emissions take place - leads to the same warming. This also means that the warming from any CO_2 source can be quantified.

A recently published scientific review of this connection (from 2023, see endnote 59), gives a relationship between future (global) warming and future CO_2 emissions. With a probability of 50 or 66 per cent to reach the 1.5°C or 2°C targets, it can be used that

100 billion tonnes of CO_2 corresponds to a global temperature rise of 0.05 °C.

Table *1* shows the temperature effect of the embedded emissions from Yggdrasil (365 million tonnes of CO_2 equivalents), Breidablikk (87 million tonnes of CO_2 equivalents) and Tyrving (12 million tonnes of CO_2 equivalents) when this connection between emissions and temperature is taken into account. Based on this, the embedded emission from Yggdrasil can be expected to result in global warming of 0.00018 ^oC.

Field (emissions in million-ton CO_2-equivalent)	**Resulting global warming** (^oC)
Yggdrasil (365)	0,00018
Breidablikk (87)	0,00004
Tyrving (12)	0,00001
Sum av de tre feltene	0,00023

Table 1: The three fields Yggdrasil, Breidablikk and Tyrvings, as well as the sum of the three fields' warming contribution to global temperature. The estimated temperature contribution is based on the relationship that 100 billion tonnes of CO_2 corresponds to a global temperature increase of 0.05 ^oC (endnote 59).

The temperature contribution from Yggdrasil may seem small. However, the total global greenhouse gas emissions from 1750 (i.e. from the start of the industrial revolution) until today have contributed to an increase in the global temperature of around 1.3^oC (Figure *1*). Compared to this, Yggdrasil contributes to global warming

The contributions from Yggdrasil to global and local climate can be illustrated in several ways:

(i) Any greenhouse gas emission leads to an increase in the Earth’s total heat content - i.e. for the Earth's atmosphere, oceans and land. Since 1960, the Earth climate system has increased its heat content by roughly 400 x 10^{21} Joules, see Figure *4*. This warming can be attributed to historical greenhouse gas emissions, which for the period 1960-2023 were 1,512 billion tonnes of CO_2 (endnote 60).

Based on this, we can estimate the contribution of Yggdrasil to increasing the Earth's total heat content. Since 1,512 billion tonnes of CO_2 have contributed to a warming of the Earth's system of 400 x 10^{21} Joules (from the previous paragraph), this means that Yggdrasil's embedded emissions of 365 million tonnes of CO_2 are equivalent to a warming of the Earth's system of 1 x 10^{21} Joules.

To put a warming of 1 x 10^{21} Joule into perspective, we can compare this with total energy production in Norway for the period 2020-2022 of around 150 TWh (endnote 61). Since 1 J = 2.78 x 10^{-16} TWh, this means that Yggdrasil's warming contribution corresponds to 180 times Norway's total annual energy production.

Similarly, Breidablikk will heat the Earth system by a factor of 43 times Norway's total annual energy production.

The main part of the heating effect of the emissions from Yggdrasil, Breidablikk and Tyrving will be found in the ocean as increased sea temperature (Figure *4)*, and will consequently contribute to increased sea levels, as well as impacting marine ecosystems for a very long time (many hundreds to several thousands years forward in time).

(ii) Any CO_2 emission, regardless of size and where the emission occurs geographically, has a very long-term warming effect on the Earth's climate. The reason for this is that current CO_2 emissions will have at least a 20 per cent warming effect 1,000 years from now (endnote 62). If we assume that a human generation is 30 years, 1,000 years corresponds to approximately 30 human generations. Consequently, the embedded emissions from Yggdrasil, Breidablikk and Tyrving will affect humanity over a very long time horizon. It is difficult to specify the consequences for societies and ecosystems over such a long time horizon, but future climate and environmental challenges and/or complications cannot be ruled out.

(iii) A fraction of any CO_2 emission will end up in the ocean. This is because CO_2 is a gas that dissolves in water. When CO_2 dissolves, the water's pH value drops. There is today a measurable drop in pH in all the World's oceans, with the fastest "acidification" in cold areas (endnote 63). It is difficult to specify the impact of the emissions from Yggdrasil, Breidablikk and Tyrving, except that they will contribute to continued acidification of the oceans globally and along the Norwegian coast/Svalbard in particular.

(iv) As the temperature of the air increases, the ability of the air to retain moisture will increase. This relationship is called the Clausius-Clapeyron equation and states that for every degree that air temperature increases, the air's ability to retain moisture increases by around seven per cent (endnote 64). This factor is a key reason why the average amount of precipitation in Norway has increased by around 20 per cent in the last 100 years (endnote 65), with an even greater increase for heavy precipitation/extreme precipitation (endnote 66). The emissions from Yggdrasil, Breidablikk and Tyrving will contribute to a continued increase in average rainfalls, as well as more extreme rainfall events, in Norway.

(v) Greenhouse gas emissions affect the Earth's energy budget (Figure *4*), including the extent of Arctic sea ice. A direct one-to-one relationship has been demonstrated between CO_2 emissions and reduced Arctic sea ice in September, which is the last "summer month" at high northern latitudes (Figure *7*). The correlation shows that for every tonne of CO_2 added to the atmosphere, the September extent of sea ice is reduced by three square metres (endnote 67).

Based on this, the embedded emission from Yggdrasil will reduce the September extent of sea ice in the Arctic by around 1,100 square kilometres. For Breidablikk, the reduction is 260 square kilometres, and for Yggdrasil, Breidablikk and Tyrving combined, the reduction is approximately 1,400 square kilometres. In comparison, Oslo's area, including Oslomarka, is 450 square kilometres.

(vi) Similar to sea ice, there is also a close one-to-one correlation between increased global warming and reduced snow cover in the northern hemisphere in spring. This applies to both observed (endnote 68) and modelled (endnote 69) snow cover.

Figure *13* illustrates this linear relationship based on several model simulations.

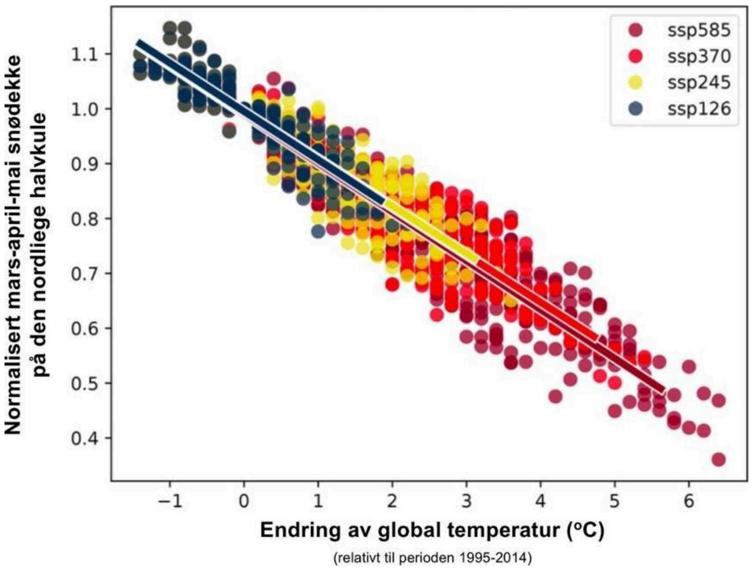


Figure 13. Relationship between change in global temperature (°C; relative to temperature for the period 1995-2014 (horizontal axis) and normalised snow cover in the northern hemisphere for the months of March, April and May (vertical axis; where a value of 1.0 corresponds to the mean extent of snow for the period 1995-2014). Based on figure 9 in endnote 69.

The relationship is that snow cover is reduced by around 8 per cent (relative to the 1995-2014 distribution of snow) for every degree Celsius of increasing global temperature.

Known, approximately linear relationships can be used to calculate the relationship between greenhouse gas emissions and reduced snow cover. This gives the following result, see endnote 70:

Emissions of 1 tonne of CO_2 correspond to 1.2 square metres of reduced snow cover.

Consequently, the embedded emissions from Yggdrasil of 365 million CO_{2e} will lead to a reduction in snow cover for the period March to May in the northern hemisphere of around 440 square kilometres. For Yggdrasil, Breidablikk and Tyrving, the reduction is approximately 560 square kilometres. In comparison, the entire area of Oslo, including forests, is 450 square kilometres.

The above applies to the northern hemisphere, for the spring months of March, April and May as a whole.

(vii) When we move upwards in the terrain, we experience that the air temperature drops. The reason for this is that the air pressure, i.e. the weight of the air above us, decreases. Typically, the temperature drops by 0.7 degrees per 100 metres of elevation. This relationship has a direct influence on the snow line. For each degree of temperature increase, the snow line will rise by approximately 140 metres. For Norway, this means that areas that are currently close to the snow line have received even less snow, or that the snow line is higher today than it was, say, 50 years ago. For Bergen, as an example, the winter temperature (November to March) has increased by 1.3 degrees over the past 50 years (endnote 71), which means that the snow line is approximately 180 metres higher today than 50 years ago. The emissions from Yggdrasil, Breidablikk and Tyrving will contribute to an increase in temperature and thus moving the snowline to higher elevations (and shortening the winter season) in Norway.

2.2 Non-linear relationship

As described above and illustrated in Figure 10, seven tipping points can be activated for global warming between 1.5°C or 2°C. Five of these tipping points will affect Norway's climate (and society and ecosystems) directly. These are the collapse of the ice cap in West Antarctica (which causes higher sea level); thawing of permafrost (which will cause unstable land/mountain slopes in the mountains and in northern Norway, and which can contribute to increased methane emissions); absence of sea ice in the Barents Sea (which will affect marine life, marine transport and access to resources); reduced vertical mixing in the Labrador Sea (which, in isolation, will weaken the Gulf Stream system); and loss of glaciers (which will change landscapes and ecosystems, affect meltwater supply and tourism).

It is not possible to specify the exact temperature threshold for when the tipping points will be activated. For the West Antarctic ice sheet, there is growing scientific support that increased melting is inevitable over the next couple of decades, possibly with the collapse of the West Antarctic ice sheet as a result (endnote 72). This is of concern since West Antarctica alone could contribute several (3-5) metres of global sea level rise.

For the Norwegian coast, assuming continued high emissions and partial collapse of the ice in West Antarctica, the sea level may rise by 1- 2 m towards the year 2100 (endnote 47).

The significant increase in global sea temperature since March 2023 (Figure *3*) and in global surface temperature since June 2023 (Figure *2*) illustrates that rapid changes in climate are occurring and that "surprises" can be expected.

For the embedded emissions from Yggdrasil, Breidablikk and Tyrving, it cannot be ruled out that these may activate one or more of the tipping points that may occur with a global temperature increase of between 1.5°C or 2°C, including the collapse of the West Antarctic ice sheet.

3. What is the world's remaining carbon budget to limit warming to 1.5 degrees and 2 degrees with a 66 percent probability?

3.1 The Paris Agreement's 1.5°C and 2°C targets

The Paris Agreement, which was adopted in 2015 and entered into force in 2016, aims to keep global warming well below 2°C compared to pre-industrial times, and asks the world's states to strive to limit the temperature increase to 1.5°C (endnote 73).

Extensive science shows that future temperature rise can be estimated based on the sum of future global emissions of CO_2 (endnote 74). The most recent estimates of future CO_2 emissions in line with the 1.5°C and 2°C targets are given in Table *2* (see also footnote 2).

Table *2* shows that there is a 50 percent probability that global temperature increases can be limited to 1.5°C if total global emissions do not exceed 200 billion tonnes of CO_2 from 2024. This corresponds to five years of current emissions (and therefore zero emissions thereafter).

If the likelihood of limiting global warming by 1.5°C is increased to 67 per cent (i.e. there is a two-thirds likelihood that global warming will not exceed 1.5°C), forthcoming global emissions cannot exceed 150 billion tonnes of CO_2, equivalent to 4 years with today's emissions and zero emissions thereafter. With an 87 percent likelihood (corresponding to a five-sixths probability), the carbon budget is 100 billion tonnes of CO_2, corresponding to 3 years of current emissions.

Climate target (°C)	**Likelihood**		
	50 %	**67 %**	**83 %**
	Global emissions in Gt-CO_2 until 2024 (Gt-CO_2 is billion tonnes of CO_2)		
1,5	200	150	100
2,0	1100	900	750
	Number of years with current emissions up to and including 2024 (global emissions in 2023 are (approx.) 37 Gt-CO_2, from endnote 75)		
1,5	5	4	3
2,0	30	24	20

Table 2: Overview of future (up to and including 2024) CO_2 emissions in line with 1.5 and two-degree warming relative to pre-industrial times with a probability of 50, 67 and 83 per cent, respectively. Future emission values in the table are from table 8 in endnote 12.

From Table 2, limiting warming to 2°C with a likelihood of 50 percent implies that today's CO_2 emissions can continue for 30 years. With a 67 percent probability, current emissions can continue for 24 years.

4. How large are the emissions of 12, 87 and 365 MtCO2e in relation to Norway's remaining share (calculated per capita) of the world's remaining carbon budget to limit warming to 1.5 and two degrees with 67 and 50 percent probability?

4.1 Norway's (domestic) greenhouse gas emissions 1958-2023

Total domestic greenhouse gas emissions in Norway since 1958 (for CO_2) and from 1990 (for all greenhouse gases) are shown in Figure *14*.

As the figure shows, Norway's domestic CO_2 emissions have increased by 8 percent between 1990 and 2023, while emissions of all other greenhouse gases (such as sulphur components, nitrogen components and methane) have been reduced by 49 percent. The reason for the latter is mainly closure/relocation of polluting heavy industry (such as magnesium production) and significantly reduced emissions from aluminium and saltpetre production (endnote 76).

In total, Norway's overall greenhouse gas emissions have been reduced by 9 per cent since 1990. For comparison, the total greenhouse gas emissions from the EU-27 countries have been reduced by 32 percent for the period 1990 to 2022 (endnote 77).

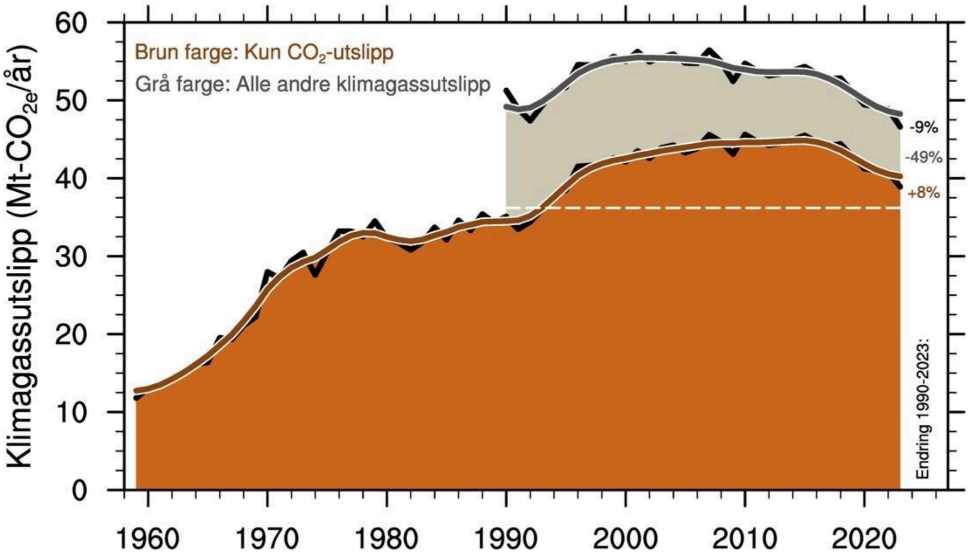


Figure 14. Total annual domestic CO_2 emissions from Norway since 1958 (brown colour), and for all other greenhouse gas emissions since 1990 (grey colour). The percentage change in emissions for the period 1990 to 2023 is shown on the right of the figure (8 per cent increase in CO_2 emissions; 49 percent reduction in emissions of other greenhouse gases; a total reduction of nine per cent). Units are million tonnes of CO_2 equivalents per year. Data from Statistics Norway, see endnote 78.

4.2 Emission pathways consistent with the 1.5 and two-degree targets

Figure 15 shows the future emissions for Norway under the assumption that the remaining global greenhouse gas emissions compatible with the 1.5°C and 2°C targets (from Table *2*) are evenly distributed among all nations, regardless of historical emissions and current economic, technological and societal developments. The Figure shows emissions compatible with limiting warming to 1.5°C and 2°C with a 50 percent probability (left), and similarly with a 67 percent probability (right).

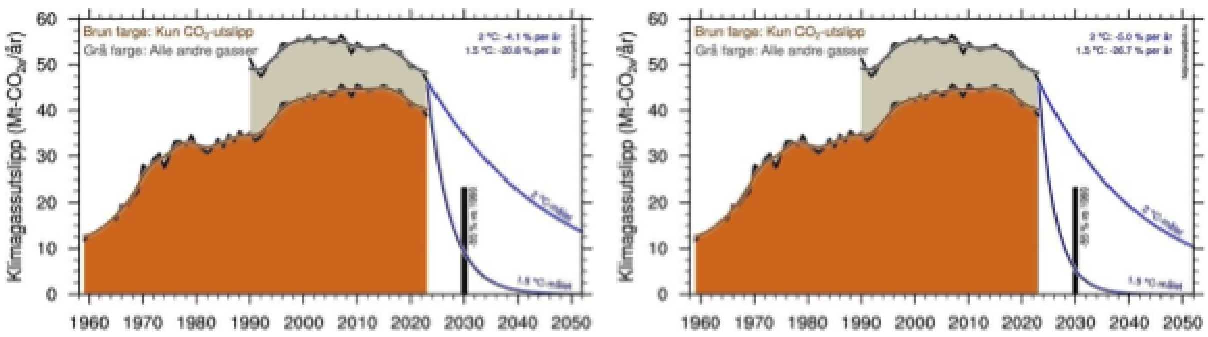


Figure 15. As Figure 14, but including Norway's 2030 climate target shown as a vertical bar (55 percent reduction in total greenhouse gas emissions relative to 1990, see endnote 79), and emission curves in line with a 50 percent probability of achieving the 1.5 and two-degree targets (left) and a 67 percent probability of achieving the 1.5 and two-degree targets (right), calculated on the basis of Table 2. Annual reductions in percent are shown at the top right of the figures. Units are million tonnes of CO_2 equivalents per year.

With a 50 percent likelihood that the global temperature will not exceed 1.5°C (left part of Figure *15*), Norway's emissions must be reduced by 21 percent per year. This corresponds *to five years of current greenhouse gas emissions in Norway* (Table *2*). Reductions in line with the 2°C target are 4.1 percent per year, corresponding to *30 years of current greenhouse gas emissions in Norway*.

For a two-thirds (67 percent) likelihood of limiting global warming to 1.5°C, Norway's emissions must be reduced by 27 percent per year, or that current emissions can continue *four years into the future*. For the 2°C target, annual emissions must be decreased by 5 percent per year, corresponding to *24 years of current greenhouse gas emissions in Norway*.

To put these stipulated emission reductions into context, Norway's greenhouse gas emissions decreased by 3.2 percent between 2019 and 2020, i.e. during the peak of the COVID-19 pandemic. Globally, total GHG emissions decreased by 5 percent during the pandemic in 2020. Based on national and global GHG emission reductions in the exceptional year 2020, Figure *15* illustrates both the magnitude and necessity of immediate GHG reductions to limit global warming to 1.5°C and 2°C.

4.3 Greenhouse gas emissions from Breidablikk, Tyrving and Yggdrasil compared to Norway's 2022 emissions

The embedded maximum emissions from Breidablikk are 87 million tonnes of CO_2 equivalents, from Tyrving 12 million tonnes of CO_2 equivalents and from Yggdrasil 365 million tonnes of CO_2 equivalents. Combined, this gives maximum emissions from the three fields of 464 million tonnes of CO_2 equivalents.

Norway's domestic greenhouse gas emissions in 2023 were 46.6 million tonnes of CO_2 equivalents (Figure *14*, endnote 80). Consequently, the maximum emissions from Yggdrasil correspond to 8 years, Breidablikk 2 years and Tyrving 0.3 years compared to Norway's greenhouse gas emissions in 2023. The sum of maximum emissions from the three fields corresponds to 10 years of Norway's greenhouse gas emissions per 2023, see Table *3*.

Emission source	CO2 equivalents (million tonnes)	Factor compared with Norway's 2023 emissions
Norway 2023	46,6	
Gross release Yggdrasil	365	**7,8**
Gross release Breidablikk	87	**1,9**
Gross release Tyrving	12	**0,3**
Sum Yggdrasil, Breidablikk, Tyrving	464	**10,0**

Table 3: Comparison of Norway's total greenhouse gas emissions in 2023 in millions of tonnes of CO_2 equivalents, with stated maximum emissions from Yggdrasil, Breidablikk and Tyrving, and the sum of emissions from the three fields

4.4 Greenhouse gas emissions from Breidablikk, Tyrving and Yggdrasil compared with the 1.5 and two-degree targets

If we again assume that the remaining global greenhouse gas emissions compatible with the 1.5^{o}C and 2^{o}C targets are evenly distributed among all nations, and we call these "residual emissions", the following applies:

1.5^{o}C target with 50 percent likelihood:

This target corresponds to 5 years of Norway's 2023 emissions (Table *2*). Since the maximum embedded emissions from Yggdrasil correspond to 7.8 years of Norway's 2023 emissions (Table *3*), Yggdrasil alone exceeds Norway's future emissions residual within the 1.5^{o}C target.

Similarly, the maximum embedded emissions from Breidablikk correspond to approximately 40 percent[2] of Norway's future emissions, while maximum embedded emissions from Tyrving correspond to six percent of Norway's future emissions.

In total for Yggdrasil, Breidablikk and Tyrving, these exceed Norway's future emissions residual within the 1.5^{o}C target by a factor of two.

[2] In order to limit global warming to 1.5 degrees with a 50 per cent probability, and given that all nations reduce their emissions by the same amount, current emissions can continue for about five years (Table *2*). Total emissions from Breidablikk correspond to 1.9 years of Norway's 2023 emissions. 1.9 years is 40 per cent of 5 years (ratio 1.9 years / 5 years). For Tyrving, the percentage is determined by the ratio 0.3 years / 5 years, or 6 per cent.

1.5°C target with 67 percent with likelihood:

This target corresponds to 4 years of Norway's 2023 emissions (Table *2*). This means that Yggdrasil alone exceeds Norway's future emissions residual within the 1.5°C target by a factor of two (relative to Norway's 2023 emissions).

The maximum embedded emissions from Breidablikk correspond to half of Norway's future residual emissions within the 1.5°C target.

For Tyrving, the emissions correspond to around eight percent of Norway's future emissions.

In total for Yggdrasil, Breidablikk and Tyrving, these exceed Norway's future emissions residual by a factor of 2.5 (relative to Norway's 2023 emissions).

2°C target with 50 percent likelihood:

This target corresponds to 30 years of Norway's 2023 emissions (Table *2)*. This means that Yggdrasil corresponds to 26 percent of Norway's future residual emissions within the 2°C target.

Similarly, the maximum embedded emissions from Breidablikk are equivalent to six percent of Norway's future emissions, while maximum emissions from Tyrving are equivalent to one percent of Norway's future emissions.

In total for Yggdrasil, Breidablikk and Tyrving, these correspond to 33 percent of Norway's future remaining emissions within the 2°C target.

2°C *target with 66 percent likelihood:*

This target corresponds to 24 years of Norway's 2023 emissions (Table *2)*. This means that Yggdrasil corresponds to 33 percent of Norway's future emissions residual within the 2°C target.

Similarly, the maximum embedded emissions from Breidablikk are equivalent to eight percent of Norway's future emissions, while the maximum embedded emissions from Tyrving are equivalent to one percent of Norway's future emissions.

In total for Yggdrasil, Breidablikk and Tyrving, these correspond to 41 percent of Norway's future remaining emissions within the 2°C target with a 66 percent likelihood.

5. Can you describe some observed climate changes in Norway?

5.1 Some observed climate changes in Norway

Observations from air, land and sea in and around Norway show clear changes in climate, especially for the last 50 years. Compared to similar changes globally and for Norway's neighbouring regions (such as the Nordic countries, the rest of Northern Europe and the Arctic), it can be concluded that these changes cannot be explained as naturally occurring variations in climate. A number of studies have shown that the main cause of ongoing climate change is man-made greenhouse gas emissions.

A review of the climate status for Norway is described in the report Climate in Norway 2100, published in 2015 (endnote 81). A new version of this report is currently being prepared. In addition, a review of sea level rise along the Norwegian coast has recently been published (see endnote 47).

A selection of examples of key climate parameters for Norway - and changes to these - are shown in Figure *16* to Figure *27*, and briefly elaborated below:

- *Average temperature Norway,* Figure *16*: The annual average temperature for Norway has increased by 1.2°C over the last 100 years, and by 1.9°C for the last 50 years. The temperature increase for Norway is thus comparable to the rate of global warming. There is an increase in temperature for all months of the year, this holds for both the last 100 years and 50 years trends.

- *Average precipitation Norway*, Figure *17*: Annual average precipitation has increased by 21 percent in the last 100 years, and by 16 percent in the last 50 years. There has been an increase in precipitation for all months of the year for the last 100 years, and for all months of the year except September and November for the last 50 years. The increase in precipitation for Norway is significantly greater than the global average.

- *Extreme precipitation Norway*, Figure *18*: Percentage number of days with "heavy precipitation"[3] expected towards the end of this century relative to the period 1971-2000. For Norway, the number of 'heavy precipitation' days is expected to increase by 30-132 per cent depending on the emission scenario, while precipitation intensity for 'heavy precipitation' days is expected to increase by 6-25 per cent depending on the emission scenario (values from endnote 82).

- *Temperature development in Oslo*, Figure *19*. The left panel shows measured change in air temperature in Oslo for the period 1837-2023. The zero value is the average temperature for the period 1901-2000. For Oslo, the temperature has increased by 1.5°C during the last 100 years, and by 1.8°C in the last 50 years.

  The right panel of Figure *19* shows a possible temperature development in Oslo if the global temperature rises by 1.4°C in this century (which is a moderate and perhaps fairly likely estimate). The year-to-year variations after 2023 are picked at random

[3] "Heavy precipitation" refers to 24-hour precipitation events that occur once or twice a year on average during the reference period 1971-2000

from observed annual temperature variations over the past 100 years. The main point of this figure is that future temperature in Oslo (as elsewhere in Norway) will be significantly different from the temperature that has been observed since the measurements started nearly 200 years ago.

- *Temperature development in Svalbard*, Figure *20*. On Svalbard, the annual average temperature has increased by 3.2°C during the last 100 years, and by as much as 5.2°C in the last 50 years. As for Oslo, we can expect a significantly changed temperature (and climate) on Svalbard in the future.

- *Snow depth, Eastern Norway,* Figure *21*. Figure 21 shows the snow depth for the months of March, April and May at the Bjørnholt measuring station in Nordmarka, Oslo, for the period 1897-2024.

  The figure shows large variations in maximum snow depth from year to year, but also a clear long-term change towards less snow. For example, the maximum snow depth at Bjørnholt for the month of April has decreased by 55 cm in the last 50 years. As a reference, the 1901-2000 average April snow depth at Bjørnholt was 91 cm.

  The long-term change at Bjørnholt can largely be attributed to global (and local) man-made warming. The change is also an illustration of a shorter winter season (later autumn and earlier spring) due to the ongoing warming. The greenhouse gas emissions from Yggdrasil, Breidablikk and Tyrving will exacerbate this development.

  If one looks at the number of days with more than 25 cm of snow at Bjørnholt, which is often used as a lower limit for (good) skiing snow, Figure *22* shows that the number of "skiing days" has decreased by 50 days since 1900; from around five months in 1900 to just over three months today.

  Since precipitation increases with increasing temperature, the total amount of snow can be expected to increase in areas with sub-zero temperatures. This means that mountain areas can generally be expected to get more snow with global warming (given that the temperature remains below zero degrees), while low-lying areas get less snow. Bjørnholt (Figure *21* and Figure *22*) is an example of the latter.

- *Number of days with snow, Norway,* Figure *23*. Change in the number of days with snow from measuring stations across Norway for the last (approx.) 100 years is shown in Figure *23*. Green circles with black outlines show locations with a statistically certain reduction in the number of days with snow. As can be seen from the figure, the number of days with snow - or the winter season - has been reduced in both southern and northern Norway. Greenhouse gas emissions from Yggdrasil, Breidablikk and Tyrving will exacerbate this trend.

- *Geohazards.* With rising temperatures and increased precipitation in the form of rain or snow, increasingly greater challenges are expected with rock, soil and snow avalanches and rockfalls on steep slopes and in the mountains. This is a recurring challenge in the Alps (endnote 83). The same is true - and is expected to increase in scope - in Norway (endnote 84). Greenhouse gas emissions from Yggdrasil, Breidablikk and Tyrving will exacerbate this development.

- *Sea level change relative to land along the Norwegian coast*, Figure *24*. For all biotypes, ecosystems, infrastructure and activities, *relative sea level*, i.e. sea level measured from land, is the relevant parameter to consider. For Norway, parts of the land have an uplift as the result of the massive ice cap during the last ice age pushing down the earth's crust. Since the ice disappeared, the land has risen, and this process is still ongoing. Vertical land uplift is greatest in the inner part of the Oslofjord and in the area around the Trondheimsfjord (40-50 cm per 100 years), while it is smallest along the southern and western coasts (around 15 cm per 100 years). Consequently, relative sea level change is greatest along the southern and western coasts, as well as in northern Norway, while the sea level falls relative to land in and near the Oslofjord and for the region from Trondheim to Lofoten, see Figure *24*.

  Since land uplift is constant while sea level rise is accelerating - and will continue to increase for thousands of years due to anthropogenic climate change (endnote 85) - rising sea levels and storm surges will become a growing problem also for Norway. A particularly large contribution to sea level rise along the Norwegian coast will come from the Antarctic ice sheet, especially if it were to collapse (see section on tipping points).

  Table 4 lists some of the main results from a recently published report on future sea level change along the Norwegian coast (endnote 47). Five emission scenarios are considered. Of these scenarios, scenario SSP3-7.0 yields a warming of 2.7^{o}C towards the end of this century, corresponding to the warming expected based on current greenhouse gas emissions and nationally reported emission targets (endnote 86).

  For emissions scenario SSP3-7.0, the most likely value for sea level rise towards the end of this century is 13 cm in Oslo, and 42 and 45 cm in Stavanger and Bergen, respectively. The difference between Oslo and the west coast is due to different degrees of land uplift.

  With a 95 percent likelihood, the sea level rise in Oslo will not exceed 57 cm, and 94 and 89 cm in Stavanger and Bergen, respectively.

  Should parts of the Antarctic ice sheet collapse, approximately 80 cm would be added to the 95 percent values given above. Future sea level rise in Oslo, Stavanger and Bergen towards the end of this century could then be as high as 156, 192 and 185 cm, respectively.

Greenhouse gas emissions from Yggdrasil, Breidablikk and Tyrving will contribute to future sea level rise globally and along the Norwegian coast. It cannot be ruled out that these emissions may contribute to activating tipping elements, such as the collapse of the West Antarctica ice cap.

- *Rot risk/damage*, Figure *25* and Figure *26*. With increasing temperature, increased humidity and increased precipitation, the risk of rot increases for all infrastructure built in wood and which is exposed to the weather, be it housing, cultural heritage sites, etc. For today's climate, the rot problem is greatest along Norway's western coastline (Figure *25*, left). In a warmer and wetter climate, today's most rot-prone areas will spread inland from the coast and to higher elevations (Figure *25* right).

  For a “business-as-usual” scenario, it is estimated that high rot risk increases from today's approximately 600,000 buildings (out of a total of 3.8 million buildings) to approximately 2.4 million buildings (Figure *26)*. Even though a business-as-usual scenario has a warming well above the 2^{o}C target, the Norwegian Environment Agency expects the risk of rot damage to increase sharply this century (endnote 87). Increased greenhouse gas emissions will increase the rot problem.

- *Marine heatwaves*, Figure *27*. Just as there are heat waves on land, there are heat waves in the sea. As a result of global warming, marine heat waves occur more frequently and with greater intensity than before (endnote 88). In the extreme, a marine heat wave can be detrimental to fish (endnote 89). For Norwegian waters, the frequency and duration of marine heatwaves have increased, particularly in the Barents Sea. For the period 1982 to 2020, more than half of all days with a marine heat wave have occurred in the last decade (endnote 90). Increased greenhouse gas emissions will increase the number and intensity of marine heatwaves.

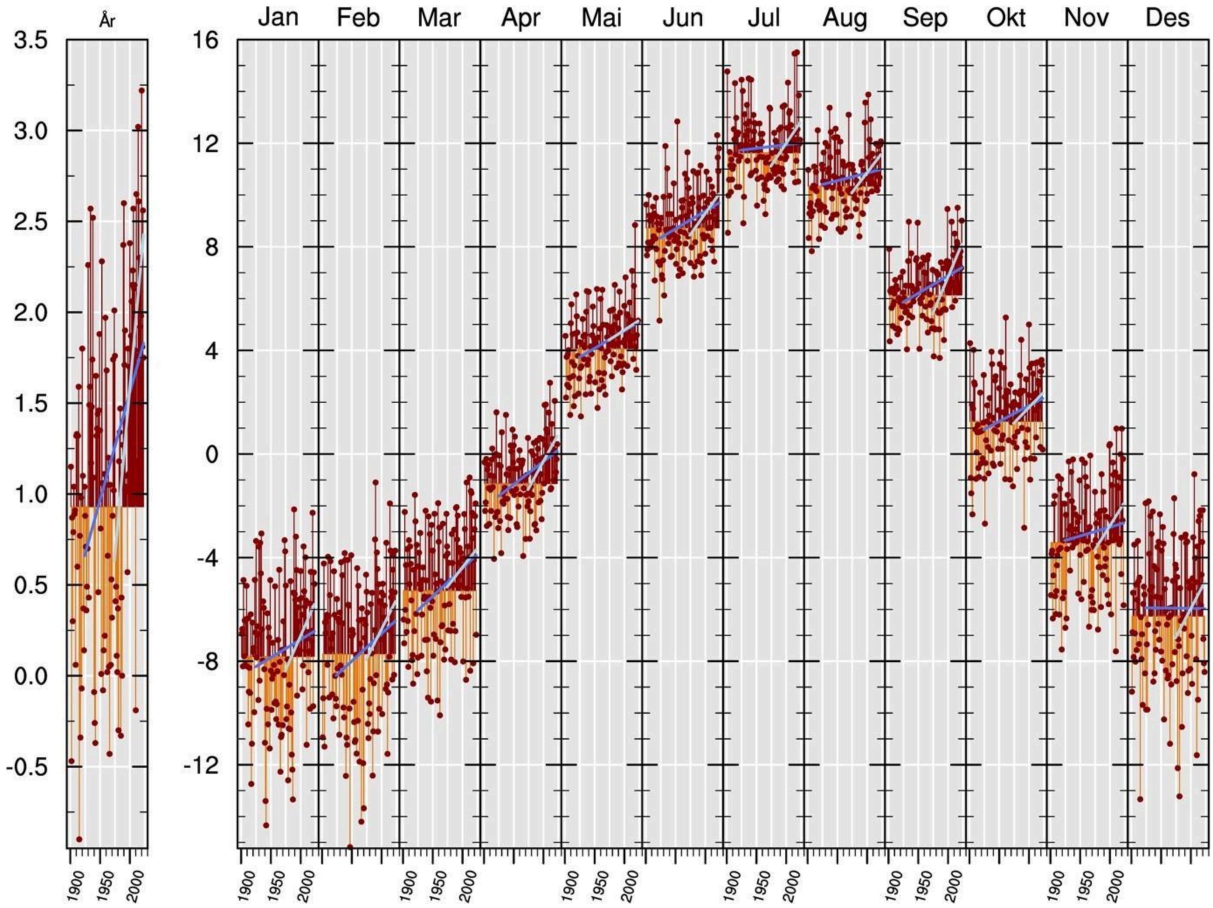


Figure 16. Observation-based annual temperature (left) and monthly temperature (right panels) for Norway since January 1900. Average temperature for the last century is shown with a transition between orange and red colour; trend over the last 100 years is shown with a dark blue line and trend over the last 50 years is shown with a light blue line. Data from the Norwegian Meteorological Institute, see endnote 91.

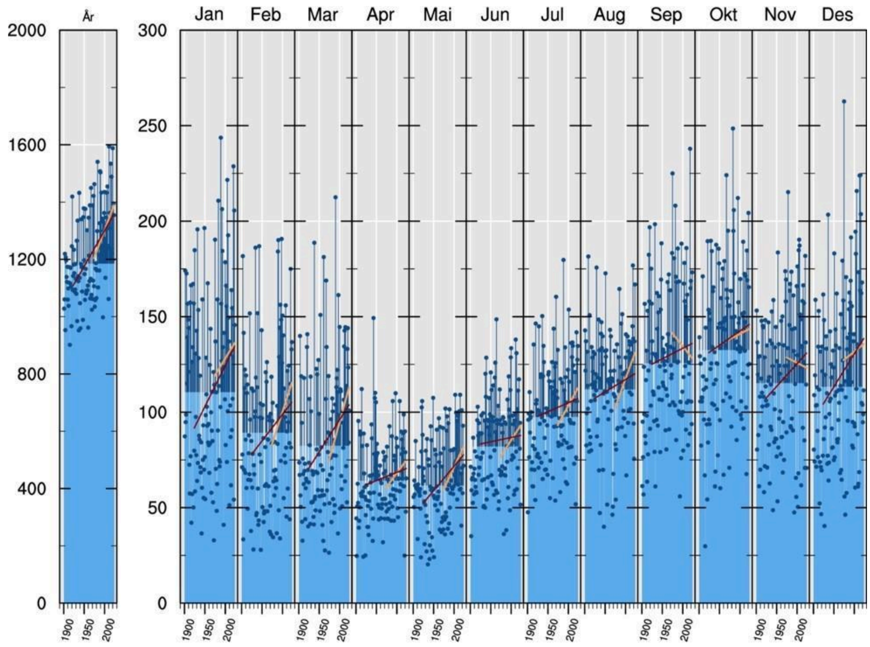


Figure 17. Observation-based annual precipitation (left) and monthly precipitation (right panels) for Norway since January 1900. The average precipitation for the last century is shown with a transition between light and dark blue colour; the trend over the last 100 years is shown with a red line and the trend over the last 50 years is shown with a yellow line. Data from the Norwegian Meteorological Institute, see endnote 92.

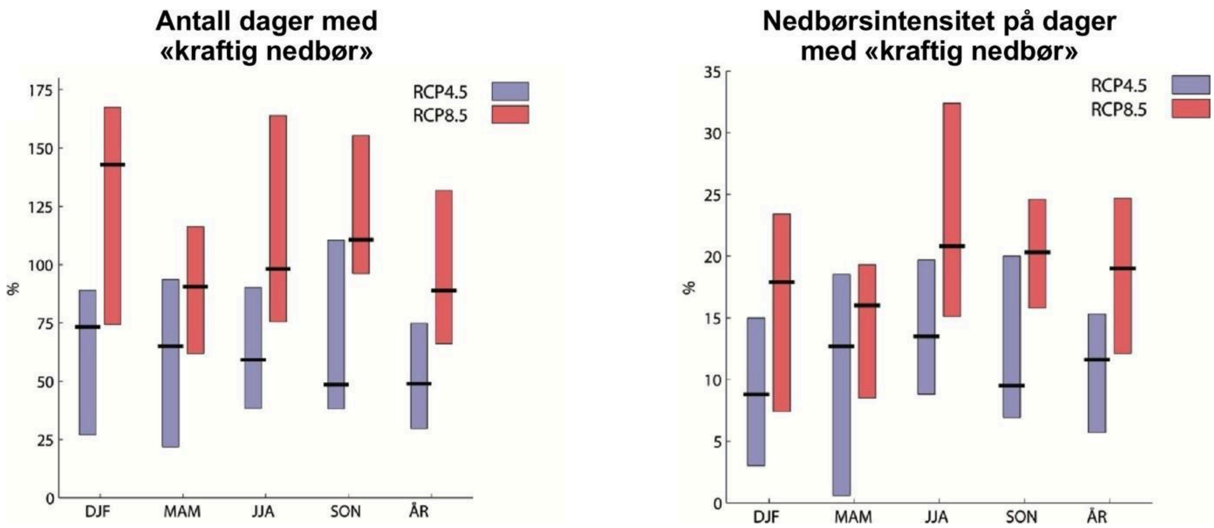


Figure 18. Left: Modelled change in percentage of days with "heavy precipitation" for Norway for the two emission scenarios RCP4.5 (intermediate scenario, gives global warming of around 2.5 degrees in 2100 relative to pre-industrial times; blue bars) and RCP8.5 (corresponding to business-as-usual emissions; red bars). Right: Similarly, but for precipitation intensity on days with "heavy precipitation". DJF is December-January-February, MAM is March-April-May, JJA is June-July-August and SON is September-October-November. Change is for the period 2071-2100 relative to the period 1971-2000, and "heavy precipitation" corresponds to 1-day events that occur on average 1-2 days per year in the reference period 1971-2000. Source, see endnote 93.

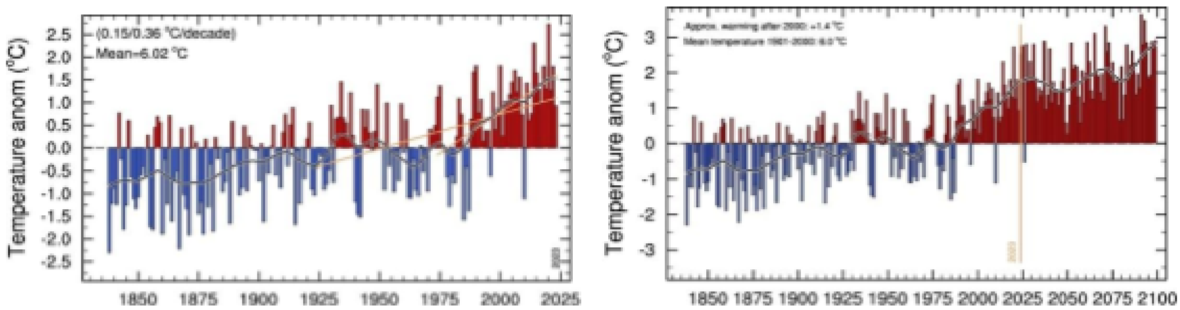


Figure 19. Left figure: Observed annual temperature change for Oslo for the period 1837-2023. Zero value is average temperature for the last century. The measured temperature increase over the last 100 years is 1.5 degrees; for the last 50 years the temperature increase is 1.8 degrees. Right figure: As the figure on the left, up to 2023, but with an assumed warming of 1.4 degrees in this century and with a random year-to-year variation going forward based on observed variation for the past 100 years. Data from the Norwegian Meteorological Institute in the figure on the left (endnote 94); temperature projection on the right by H. Drange.

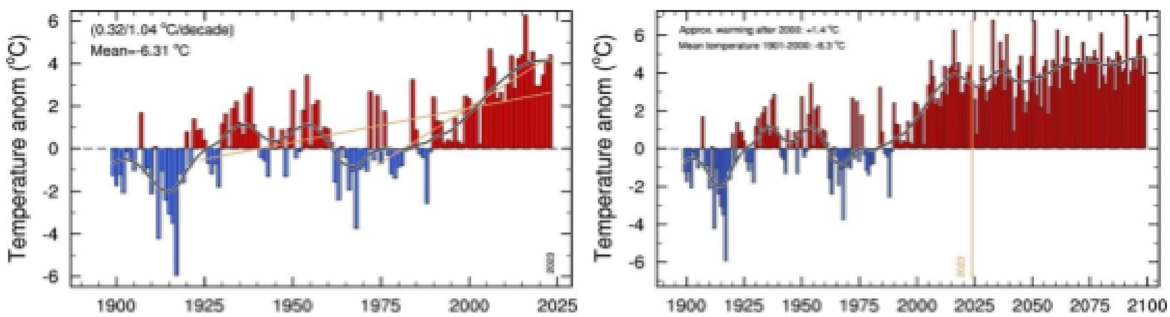


Figure 20. Same as Figure 19, but for Svalbard since measurements began in 1899. The measured temperature increase over the last 100 years is 3.2 degrees; for the last 50 years, the temperature increase is (as much as) 5.2 degrees.

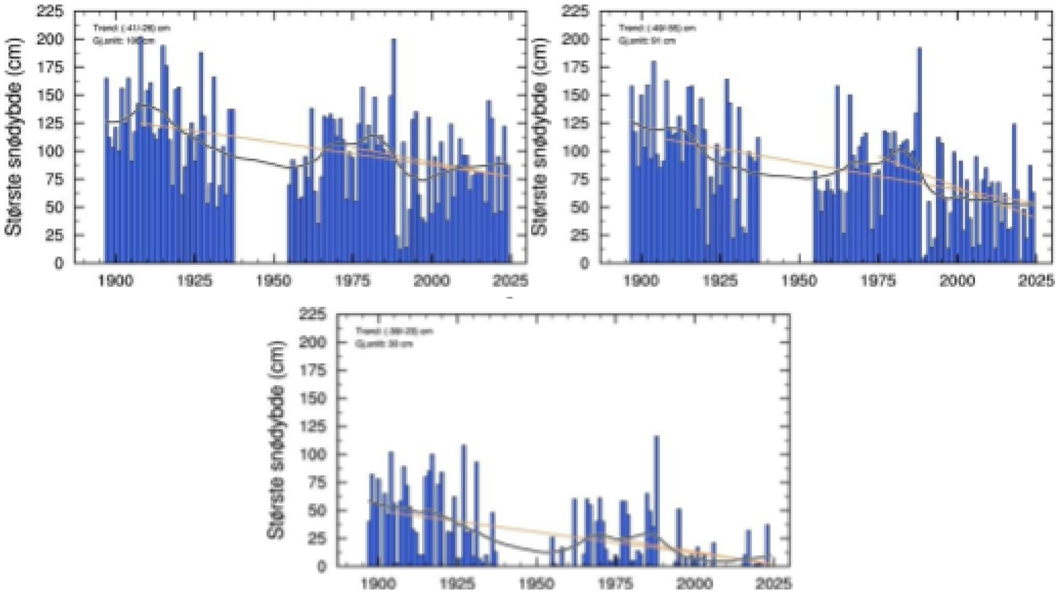


Figure 21. Maximum measured snow depth (cm) at Bjørnholt in Nordmarka, Oslo (360 m above sea level) for the months of March (upper left figure), April (upper right figure) and May (lower figure) for the period 1897-2024. Trend values (cm) show the change in the greatest measured snow depth for the last 100 and 50 years, respectively. "Average" is the average of the greatest snow depth for the previous century (1901-2000). Data from the Norwegian Meteorological Institute, available from https://frost.met.no.

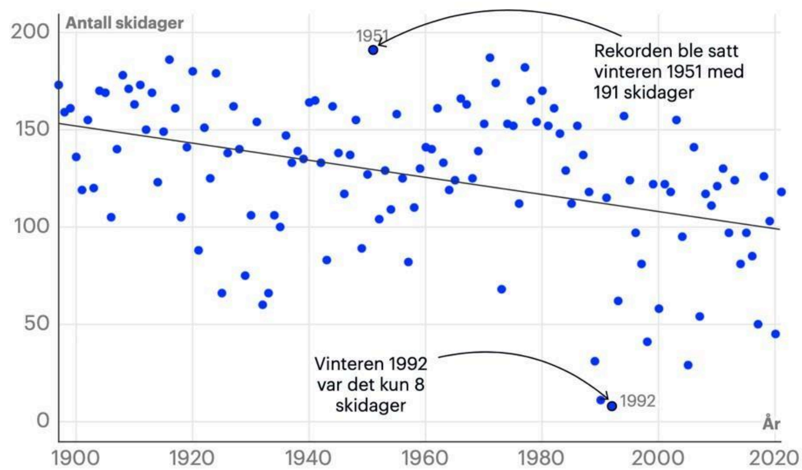


Figure 22. Number of days with more than 25 cm of snow at Bjørnholt in Nordmarka, Oslo. Figure from Aftenposten 15 May 2021 (https://www.aftenposten.no/oslo/i/Ga99Ll/en-knallvinter-er-over-for-skifolket-men-paa-sikt-blir-sesongene-kortere) based on measurements from the Norwegian Meteorological Institute.

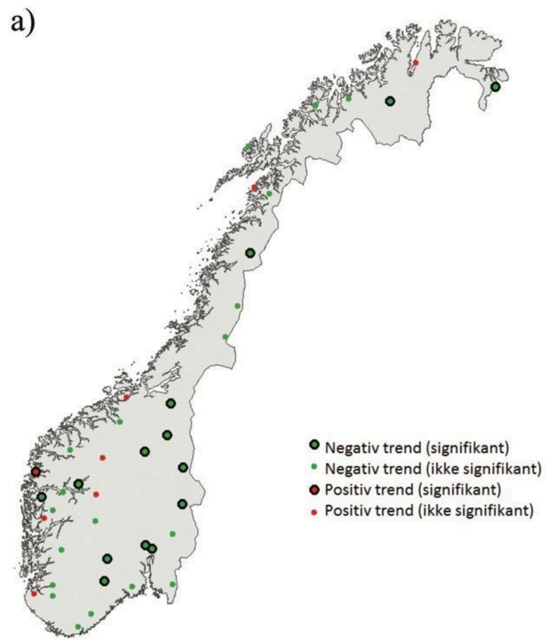


Figure 23 (a) Change in the number of days with snow for various measuring stations in Norway; green circles with black highlighting show locations where there has been a significant (statistically significant) decrease in the number of days with snow over the past (approx.) 100 years. From Figure 3.3.10a in "Climate in Norway 2100", https://klimaservicesenter.no/kss/rapporter/kin2100.

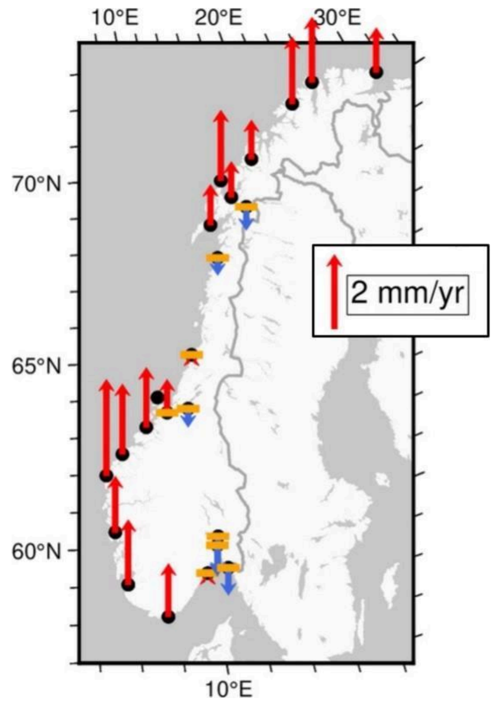


Figure 24. Observed sea level change relative to land (mm/year) along the Norwegian coast for the period 1984-2014. Red arrows show rising sea level relative to land; blue arrows show falling sea level relative to land. Source endnote 95.

						Lav sannsynlighet, stor konsekvens	
Utslippsenario:	**SSP1-1.9**	**SSP1-2.6**	**SSP2-4.5**	**SSP3-7.0**	**SSP5-8.5**	**SSP1-2.6**	**SSP5-8.5**
Oppvarming 2081-2100:	1.4	1.8	2.7	3.6	4.4	1.8	4.4
Oslo Median endring	-5	1	13	21	32	0	39
5 til 95 % utfallsrom	-48 til 45	-31 til 43	-18 til 57	-15 til 74	-7 til 91	-37 til 46	-12 til 156
Stavanger	28	33	45	55	65	33	75
	-17 til 80	-4 til 80	10 til 94	16 til 109	24 til 126	-10 til 82	18 til 192
Bergen	0.25	0.30	42	51	61	29	68
	-20 til 75	-5 til 76	9 til 89	12 til 105	21 til 121	-12 til 78	13 til 185
Heimsjø/Trh	7	12	23	30	41	10	51
	-34 til 57	-23 til 57	-11 til 70	-8 til 84	1 til 100	-23 til 58	-10 til 160
Tromsø	14	16	27	34	44	13	53
	-29 til 63	-21 til 62	-9 til 75	-6 til 89	4 til 104	-33 til 63	-13 til 159
Honningsvåg	19	20	32	39	49	18	56
	-19 til 64	-17 til 66	-4 til 81	1 til 92	11 til 108	-28 til 67	-4 til 165

Table 4. Projection of relative sea level (cm) along the Norwegian coast for four emission scenarios (SSP1-1.9 to SSP5-8.5). The sea level values are median (mean) change and change with between five and 95 per cent probability, with values given for the period 2081-2100 relative to 1995-2014. The four emission scenarios result in global warming of 1.4, 1.8, 2.7, 3.6 and 4.4 ºC respectively. The two columns on the right represent scenarios with rapid melting of the ice caps in Greenland and Antarctica.

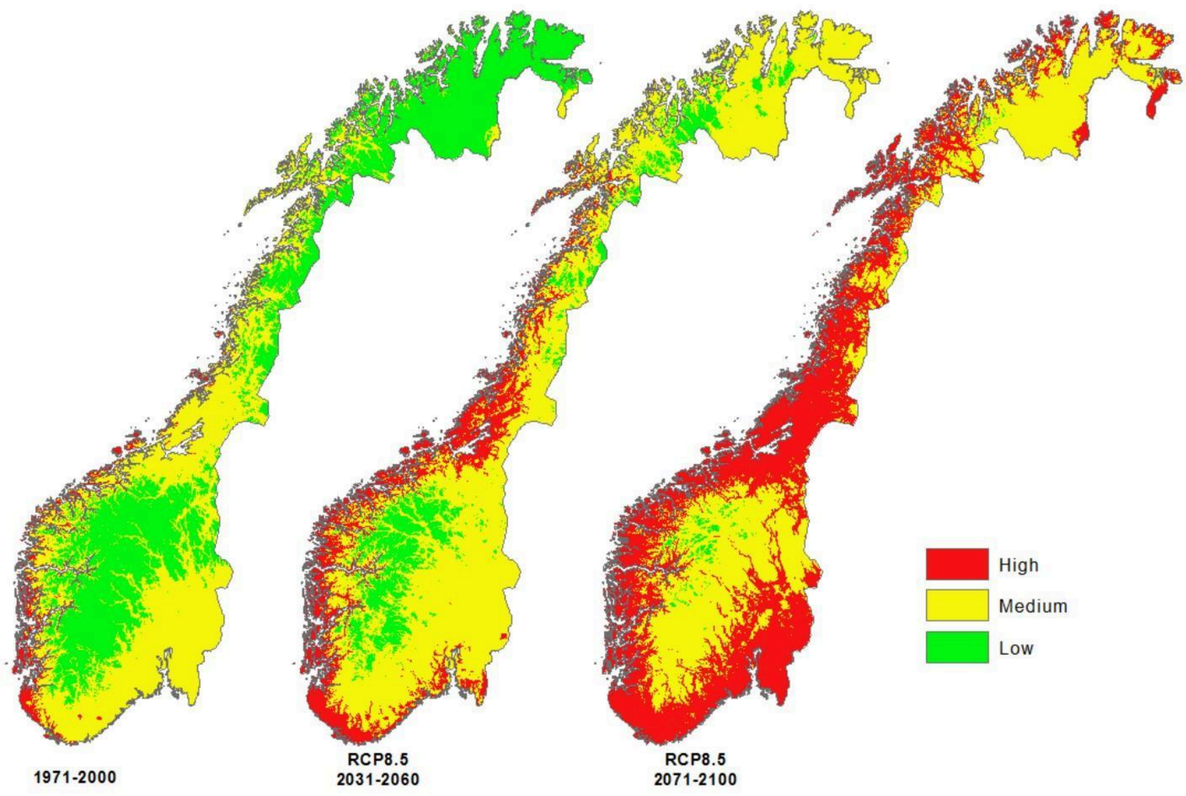


Figure 25. Rot risk in Norway based on "today's" climate (left figure) and for two time periods in the future, for 2013-2060 (centre figure) and for 2071-2100 (right). The colouring shows areas with high, moderate and low rot risk in red, yellow and green colours respectively. A "business-as-usual" scenario is used as the future scenario. Source, see endnote 96.

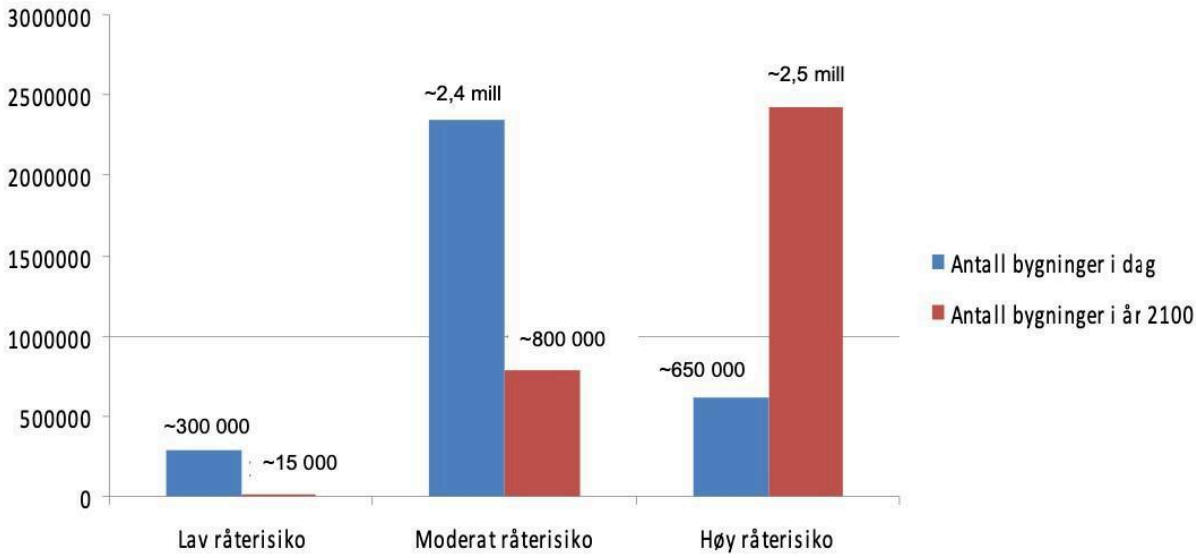


Figure 26. Number of buildings for mainland Norway with low, moderate and high rot risk for the current climate (blue colour) and climate in 2100 based on a business-as-usual scenario (red colour). Only existing buildings are included. Source, see endnote 97.

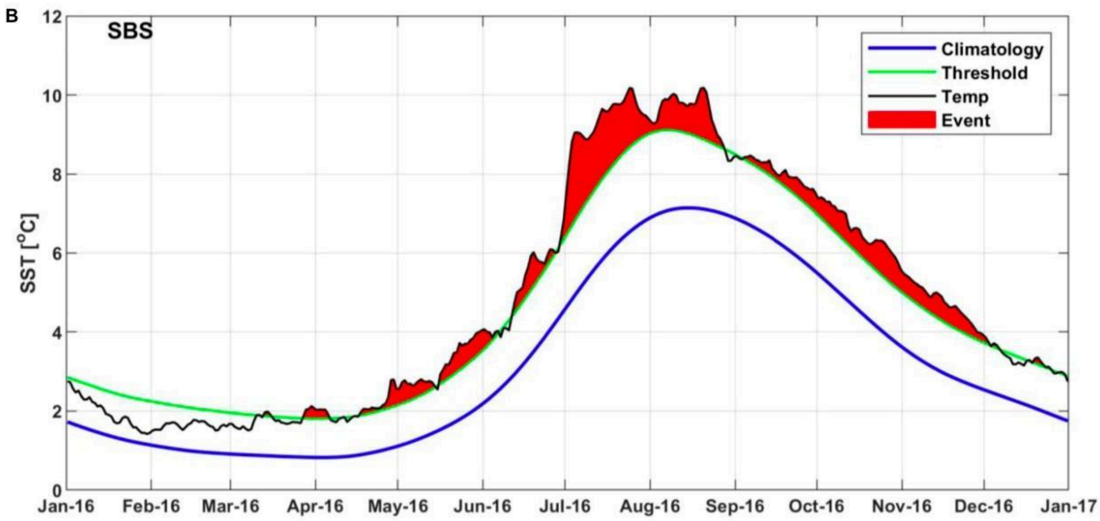


Figure 27: Illustration of sea temperature throughout the year (for 2016) in the southern Barents Sea. The blue curve shows the average (climatological) temperature variation throughout the year, while the black curve shows the actual temperature in 2016. The green curve defines when a marine heatwave occurs in the area, and the red colour indicates ongoing marine heatwaves. Figure, see endnote 98

5.2 Registered climate-related insurance claims and payouts in Norway

Figure 28 shows the number of registered insurance claims and associated insurance payments in Norway for the period 1980-2023. In this overview, natural damage includes the combined contribution from storms, storm surges, floods and landslides. There is a tendency towards more insurance claims, and in particular increased insurance payouts.

The insurance payouts caused by storms, storm surges, floods and landslides in 2023 is approximately NOK 4 billion (see Figure 28). Water intrusion, frost and lightning damage adds to this, yielding a total of NOK 7.4 billion (endnote 99). The single, major event in 2023 was the extreme weather event *Hans* on 7-9 August, affecting large parts of eastern Norway with significant flood and storm water damage (endnote 100).

In addition to the above, there are uninsured assets and damage to state property. To date, the Government has set aside NOK 1.7 billion for flood-affected municipalities and districts, of which NOK 1 billion was allocated in February 2024 (endnote 101). The total cost of weather and natural disasters in 2023 is therefore around NOK 9 billion.

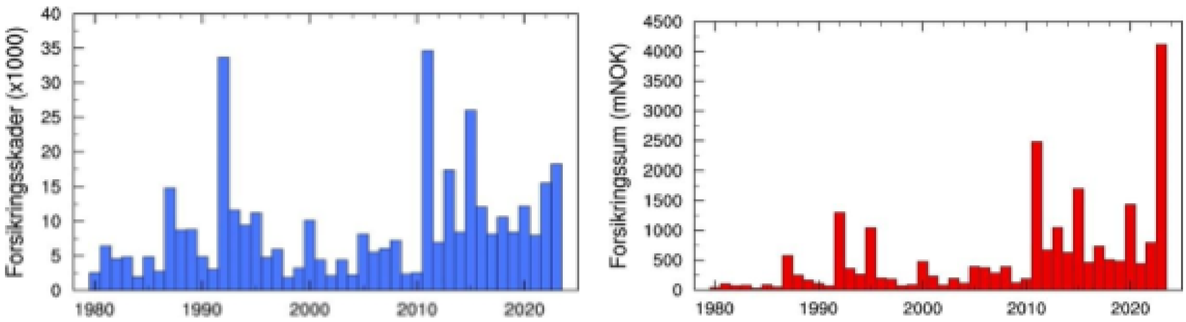


Figure 28: Total number of registered natural perils from storms, storm surges, floods and landslides (left figure) and associated sum insured (in NOK million; right figure) in Norway for the period 1980-2023. Data from endnote 102.

6. Will these emissions have an impact on climate change in Norway and contribute to damage?

The latest main report from the Intergovernmental Panel on Climate Change concludes that

> "Every tonne of CO_2 emissions adds to global warming" (endnote 10), and
> "With every additional increment of global warming, changes in extremes continue to become larger" (endnote 11).

The greenhouse gas emissions from Breidablikk, Tyrving and Yggdrasil, individually or in total, are no exception to the above conclusions.

In addition, it cannot be ruled out that greenhouse gas emissions from Breidablikk, Tyrving and Yggdrasil, individually or in total, may activate one or more of the tipping points discussed above (Figure 10).

The maximum emissions from Breidablikk, Tyrving and Yggdrasil - even if all other emissions from Norway were to be zero from 2024 - would mean that Norway exceeds emissions that would be compatible with the 1.5°C target by a factor of two (with a 50 percent likelihood of reaching the 1.5°C target) and a factor of 2.5 (with a 67 percent likelihood of reaching the 1.5°C target).

For the 2°C target, the maximum emissions from Breidablikk, Tyrving and Yggdrasil correspond to between 30 and 40 percent of the sum of all other future greenhouse gas emissions from Norway.

Sections 1 and 5 list some observed climate indicators for Norway/the northern regions:

Average temperature
Average precipitation
Extreme precipitation
Temperature development Oslo and Svalbard
Snow depth
Number of days with snow
Geohazards
Sea level change relative to land
Rot risk/damage
Marine heatwaves
Ocean acidification
Ice extent in the Arctic
Snow limit

All of these indicators are changing, and it has been thoroughly scientifically documented that the changes are - for the most part - due to man-made greenhouse gas emissions (endnote 103). The changes will be amplified by new greenhouse gas emissions.

It is possible to quantify the contributions from Breidablikk, Tyrving and Yggdrasil on key climate indicators:

As an example, the maximum emissions from Yggdrasil will increase the global average temperature by 0.00018°C, k by 0.0004°C from Breidablikk and by 0.00001°C from Tyrving. The total contribution from these fields to the global average temperature is 0.00023°C (Table *1*). Future temperature development for Norway can be expected to be on a par with, or up to a factor of two greater than, the global average value (endnote 104). In comparison, the accumulated global greenhouse gas emissions from 1750 (i.e. from the start of the industrial revolution) until today have contributed to an increase in global temperature of 1.3 degrees (Figure *1)*.

Yggdrasil will contribute to warming the Earth system equivalent to 180 times Norway's total annual energy production. Similarly, Breidablikk will warm the Earth system by a factor of 43 times Norway's total annual energy production

The temperature contribution from Breidablikk will result in a reduction of 261 square kilometres of sea ice in the Arctic in September. For Yggdrasil, Breidablikk and Tyrving combined, the reduction is approximately 1,400 square kilometres.

Similarly, the maximum emission from Yggdrasil will reduce the extent of snow in the northern hemisphere in May by around 440 square kilometres. For the three fields as a whole, the reduction is 560 square kilometres. In comparison, Oslo municipality, including Oslomarka, is 450 square kilometres.

The air's ability to retain moisture increases by approximately 7 percent per degree increase in air temperature. Increased air temperature will therefore lead to increased precipitation (provided there is a source of moisture, which is generally the case for Norway with its large, neighbouring sea areas). Breidablikk, Tyrving and Yggdrasil will therefore contribute to increased precipitation, including extreme precipitation.

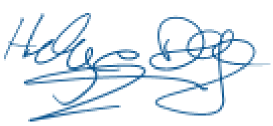
The combination of increased temperature, increased humidity and more rain means that the risk of rot is increasing for buildings, including weather-exposed wooden cultural monuments. Breidablikk, Tyrving and Yggdrasil will contribute to a worsening of the rot problem in Norway.

The snow line is often found where the temperature is around zero degrees in winter. For every degree the temperature increases, the snow line will rise by approximately 140 metres in the terrain. For Norway, Breidablikk, Tyrving and Yggdrasil will contribute to the snowline rising and the winter season shortening.

Sea levels are rising mainly due to rising sea temperatures and the melting of glaciers and ice caps in Greenland and Antarctica. Both factors will increase with rising temperatures. Breidablikk, Tyrving and Yggdrasil will contribute to global - and local - sea level rise. If the warming from Breidablikk, Tyrving or Yggdrasil causes the ice cap in West Antarctica to collapse - which is one of the tipping points that can occur with a global temperature of between $1.5^{o}C$ and $2^{o}C$ - global and local sea levels will rise by several metres. This will obviously have major consequences for societies and ecosystems globally and for Norway.

Increased sea temperatures will also lead to more intense marine heatwaves. As far as Norway is concerned, the Barents Sea is particularly vulnerable, with consequences for ecosystems and fisheries.

Bergen, 22 June 2024



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30 million $km^2 = 3 \times 10^7 km^2$.

Since snow cover decreases by around 8 per cent (relative to 1995-2014 snow cover) for each degree of increase in global temperature, the linear relationship can be expressed as warming of 1 degree Celsius corresponds to

$0.08 \times (3 \times 10^7 km^2) = 2.4 \times 10^6 km^2$ with reduced snow cover.

Furthermore, from the linear relationship between global warming and greenhouse gas emissions (from Lambol et al. (2023) in *Nature Climate Change*, https://doi.org/10.1038/s41558-023-01848-5) at

100 billion tonnes of CO_2 corresponds to a warming of 0.05 ^oC, or

$2x10^{12}$ tonnes of CO_2 corresponds to a warming of 1 ^oC.

Combined, the two relationships above mean that a

greenhouse gas emissions of $2x10^{12}$ tonnes CO_2 results in $2.4 \times 10^6 km^2$ reduced snow cover, or simplified that

1 tonne of CO_2 corresponds to 1.2 square metres of reduced snow cover.

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