EXPERT OPINION

Application number:	34068/21
Date:	12 August 2024
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Assessment of climate consequences for Norway from emissions from oil and gas resources in the Barents Sea South and Barents Sea South-East regions

0. Introduction

a. Background: The law firm *Simonsen Vogt Wiig* has requested a written statement addressing the climate consequences of the emissions embedded in the estimated oil and gas resources in the Barents Sea South and Barents Sea South-East regions.

b. Mandate: I have been requested to respond to the following mandate:

In the context of the proceedings of Greenpeace Nordic and others v. Norway (app. no. 34068/21) before the European Court of Human Rights, the applicants (Greenpeace Nordic, Nature and Youth Norway and six individual applicants) are seeking an expert analysis of the climate consequences in Norway from the embedded emissions in the estimated resources of the Barents Sea South-East (BSSE) and the Barents Sea South (BSS). Using the Norwegian Statistical Bureau's emission factors, the resource estimates for the BSSE in Meld. St. 46 (2012-2013) 36 p. 6 correspond to 132 (minimum), 722 (median) and 1627 (maximum) MtCO2. An earlier production scenario for the BSSE corresponds to 106,9 (low) and 388 (high) MtCO2. The resource estimates for the BSS in St. Meld. 40 (1988-1989) p. 14 correspond to 2880 (minimum), 5184 (median) and 6336 (maximum) MtCO2, assuming 20% oil and 80% gas.

The applicants ask the undersigned to answer the following questions, based on best available science:

1. *Can you summarise climate science status of relevance for your assessment?*
2. *Can you describe some observed and projected climate changes in Norway?*

3. *What was the World's remaining carbon budget to limit warming to 1,5°C and 2°C with 50, 67 and 83 percent likelihood per 2023?*
4. *What is the magnitude of the emissions embedded in the Barents Sea South and Barents Sea South-East resource estimates (medium and maximum) compared to Norway's annual territorial emissions?*
5. *What are some climate consequences of these embedded emissions in the Barents Sea South and Barents Sea South-East for linear and non-linear changes in climate in Norway?*

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 stiftelens* 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 status of relevance for 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 Earth's climate for 1,000 years or more.
- For the first time, there is now sufficiently strong observational, theoretical, and modelling knowledge to conclude that not only the long-term average climate, but also extreme weather events, are affected 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 – that is, rapid, irreversible changes in climate – increases with increasing greenhouse gas emissions.
- Of seven identified tipping points that can be activated when global warming increases from 1.5°C to 2°C, five will affect Norway directly. These are the collapse of the ice sheet in West Antarctica (resulting in higher sea level); thawing of permafrost (leading to unstable land/mountain slopes, and which can contribute to increased emissions of methane); 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).
- The emissions related to the updated resource estimates for the Barents Sea South and the Barents Sea South-East regions are substantial compared to Norway's domestic annual emissions; exceeding the latter with a factor between 130 and 170 (Table *3*).
- With the assumption that future greenhouse gas emissions are evenly distributed among all nations, the median emissions from the Barents Sea South and Barents Sea South-East exceeds Norway's "residual emissions" within the 1.5°C target by a factor 24 or more (Table *4*). For maximum emissions from the Barents Sea South and Barents Sea South-East, the factor is 32 or higher. In this perspective, emissions from the Barents Sea South and Barents Sea South-East are incompatible with the 1.5°C target.
- For the 2°C target, the median and maximum emissions from the Barents Sea South and Barents Sea South-East regions exceed Norway's "residual emissions" by a factor 4.3 and 5.8, respectively, which is also incompatible with the 2°C target.
- It cannot be ruled out that the greenhouse gas emissions from one or both of the Barents Sea regions may activate one or more of the tipping elements mentioned above, with unprecedented impacts on ecosystems and human societies.

1.2 Background

The warming effect on the Earth's climate by water vapor and various gases 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 consequence of this is that increasing amounts of heat-trapping gases in the atmosphere will add an additional warming to Earth's surface. This is exactly what is happening (endnote 3).

Well-established scientific knowledge about man-made global warming – where carbon dioxide (CO_2) as a result of the extraction 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 (endnote 4), 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".

The 2021 Nobel Prize in Physics was awarded to the Professors Syukuro Manabe (USA/Japan), Klaus Hasselmann (Germany) and Giorgio Parisi (Italy) for their contribution to the understanding of the Earth's climate system and other complicated 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 generation, we have to act now in a very fast way" (endnote 6).

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

1.3 The latest report from the *Intergovernmental Panel on Climate Change, IPCC*

The Sixed Assessment Report (AR6) from the UN's *Intergovernmental Panel on Climate Change* (IPCC) was published in 2021-2023 (endnote 3). Two of the key summary statements from Working Group One, reviewing all available specialist literature addressing the physical climate system, are (endnote 7):

> "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 an acronym for "Assessment Report Five"; it is the previous main report from the IPCC, published in 2013/14).

The first of the above quotes states that it is a scientifically established fact – implying no scientific uncertainty – that burning of coal, oil and gas, as well as use of land, have changed all parts of the Earth's climate.

The second quote is of particular importance for all life on Earth: There is now sufficient observational, theoretical, and modelling knowledge to conclude that not only the long-term, average climate, but also extreme weather events, are affected by man-made greenhouse gas emissions.

In addition, the latest IPCC report concludes that any greenhouse gas emissions will intensify global warming (endnote 8):

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

and regarding the relationship between intensified global warming and extreme weather events (endnote 9):

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

Changes in climate have also non-human, often called naturally occurring, causes. Factors such as variations in the Sun's radiation, frequency and intensity of volcanic eruptions, and redistribution of heat between the ocean surface and its abyss are factors belonging to the last group. Naturally occurring variations on Earth's climate is, however, negligible compared to the human-induced contribution, at least on global scales and for timescales longer than a decade.

Regarding the latter, a recent publication[1] concludes that global warming during the period 2014-2023 is in practice fully (close to 100 per cent) man-made, continuing a similar conclusion for the period 2010-2019 from the latest IPCC report (endnote 10):

> "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 contribution of Working Group One (WG1) to the sixth (and latest) main report from IPCC, published in 2021).

1.4 Some examples of observed changes in climate

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

(1.4a) Global surface temperature since 1850

A compilation of the six most used analyses of annual mean, global temperature is shown in Figure *1*. All time series show a steady increase in the global temperature over the last 70 years, and that 2023 was, by a clear margin, the warmest year since instrumental observations started around 1850.

[1] The publication (endnote 10) is an annual update of the most central climate indicators that are reviewed by IPCC every six to seven years.

Year 2023 was about 1.4°C warmer than the 1850-1880 mean (Figure *1*). A more robust estimate of the long-term global warming can be found by considering the trend line of global temperature for the last 20 years and comparing this with the 1850-1880 mean temperature. With this method, the global warming since pre-industrial times is 1.29 °C (the difference between the endpoints of the green lines in Figure *1*). Hereafter, a global warming of 1.3 °C relative to pre-industrial times is used in this statement.

It is likely that the current global temperature – if it continues at today's value (which is highly likely) – is higher than at any time in the last hundred thousand years, perhaps even further back in time (endnote 11).

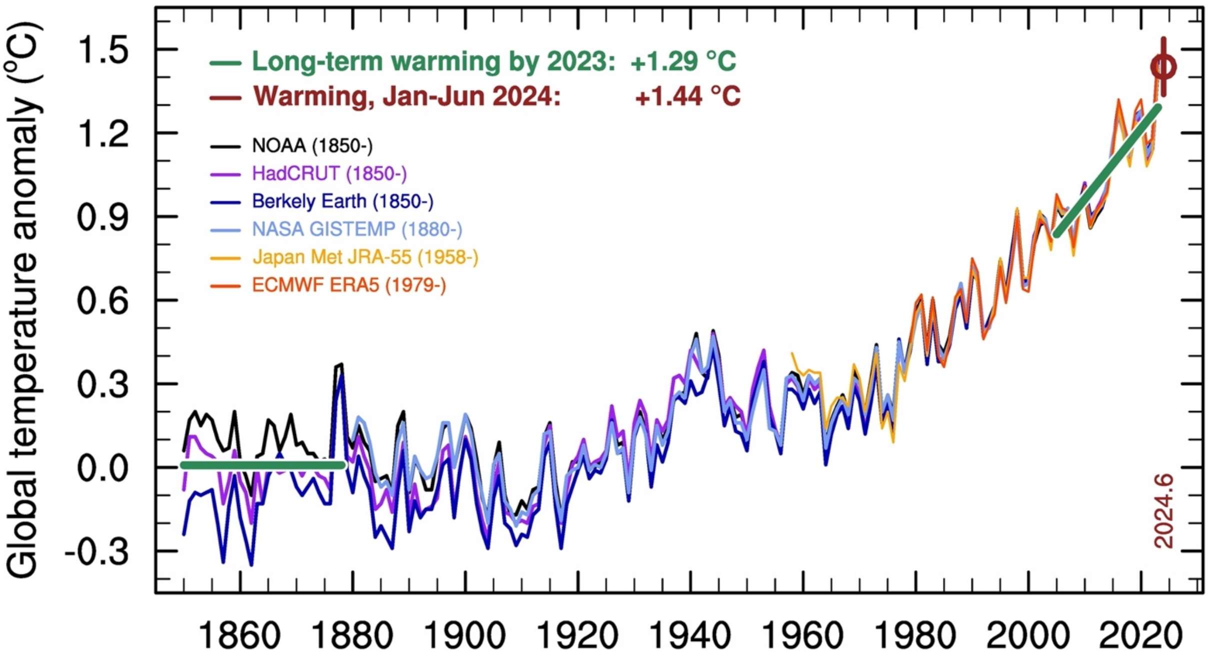

Figure 1. Change in the annual mean global surface temperature since 1850-1880 from six different global temperature analyses; three from the USA (NOAA, Berkeley and NASA), two from Europe (HadCRUT and ECMWF) and one from Japan (JRA-55). The difference between the end-points of the thick green lines gives a long-term warming in 2023 relative to the 1850-1880 mean of +1.29°C. The global temperature in 2024 is estimated to end between +1.34°C and +1.54°C relative to the 1850-1880 mean, with a central estimate of +1.44°C (red vertical line and circle).

Regarding the time series: The analyses starting in 1850 and 1880 are all based on observed surface temperature recordings, 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 common period 1981–2010, with a temperature 0.69°C lower for the period 1850–1900 (0.69°C is an estimate of the warming between the two periods based on the latest main report from the UN Climate Panel). The time series have an estimated accuracy of around ±0.05°C after 1950, increasing to ±0.1°C one hundred years ago (endnote 12). Data available from endnote 13.

(1.4b) Global surface temperature, 2024

As shown in Figure *1*, global warming continues at a record level in 2024. Based on the months January to June 2024, the annual mean 2024-temperature can be expected to end at 1.44±0.10°C, or close to a 1.5°C warming relative to the pre-industrial temperature (see also endnote 14).

(1.4c) The 1.5°C target

As Figure *1* illustrates, the annual mean temperature in 2023 and 2024 is approaching 1.5°C above the pre-industrial temperature, the latter defined as the average temperature for the period 1850-1880.

Specifically, and for the first time since temperature measurements began around 1850, all days in 2023 were more than 1°C warmer than pre-industrial times. In addition, 173 days in 2023 – or around half of the year – had a temperature of more than 1.5°C above pre-industrial temperature (endnote 15).

The monthly mean temperatures of January to June 2024 have been even warmer than those in 2023.

(1.4d) Importance of 1.5°C warming

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

(1.4e) Arctic amplification

Global warming is not evenly distributed; land warms faster than the ocean, and the Arctic warms much faster than the global mean. The latter is illustrated in Figure *2*, comparing changes in global mean surface temperature and temperature poleward of 60° N.

Whereas the long-term global mean surface warming is about 1.3°C (Figure *1*), the Arctic has warmed more than two times as much (endnote 16). There are several reasons for this so-called Arctic, or polar, amplification. Reduced loss of heat to space in the polar regions, much reduced sea ice extent in summer and fall, as well as reduced snow cover in spring, summer and fall, are all contributing factors (endnote 17).

For Norway, Arctic amplification is particularly evident in the archipelago of Svalbard between 74° and 81° N. At the meteorological station in Longyearbyen at 78° N, the annual mean temperature has increased by 3.2°C during the last 100 years, and a full 5.2°C during the last 50 years (further discussed in relation to Figure *17*). An important reason for this dramatic warming is the loss of sea ice throughout most of the year, the polar winter included.

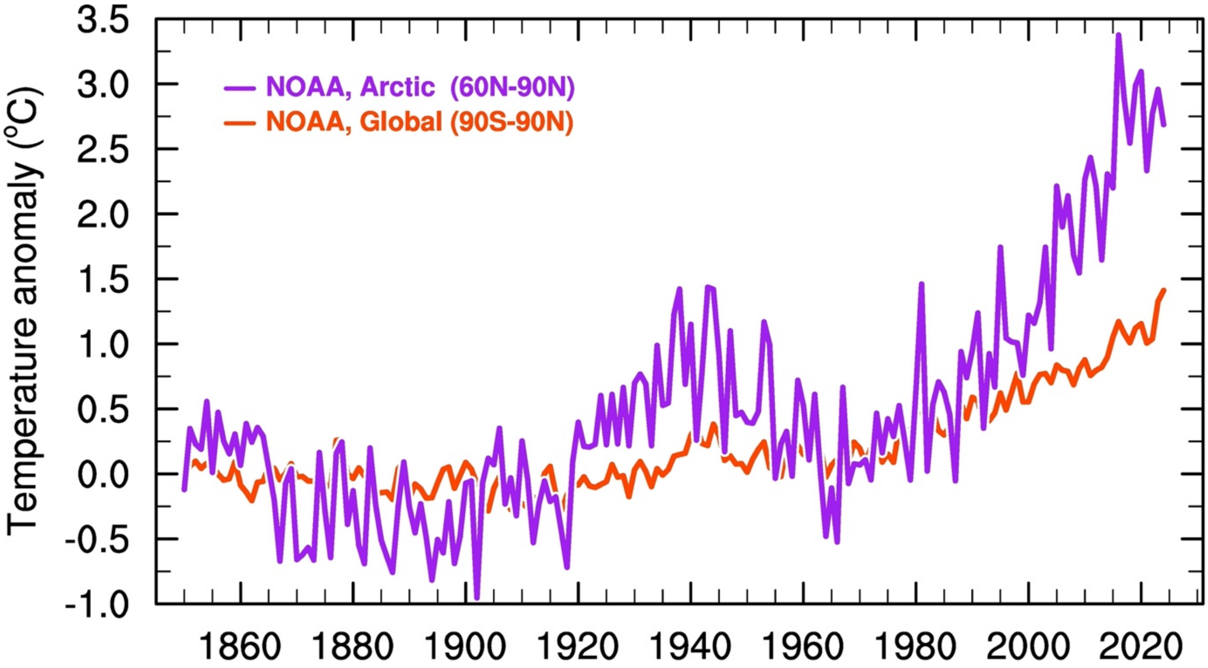

Figure 2. Comparison between observation-based change in annual mean, global temperature (red line, in °C) and the annual mean temperature poleward of 60° N (purple line), between 1850 and June 2024. Zero anomaly is the mean temperature for the period 1850-1880. Data source in endnote 18.

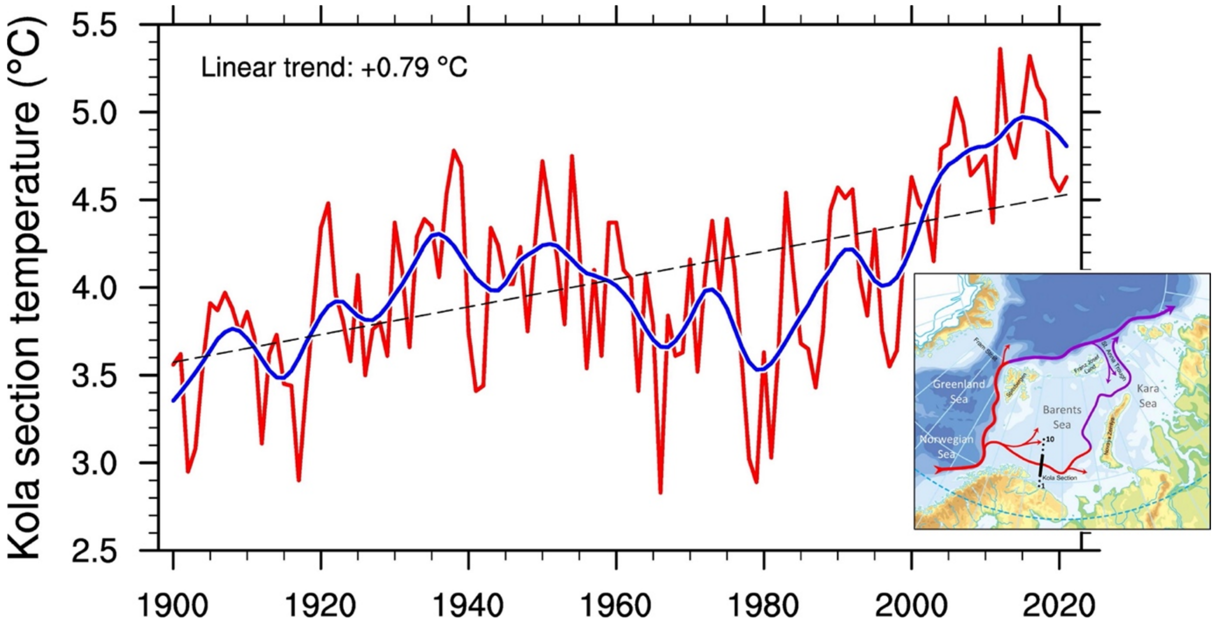

Figure 3. Annual mean temperature (°C, red line) along the Kola Section in the southern Barents Sea, the latter shown as the black line on the map. The section is 220 km long and the temperature is averaged over the uppermost 200 m of the water column. The blue curve is a smoothed version of the annual mean temperature, whereas the dashed line shows the linear trend of +0.79°C since 1900. Data in endnote 19.

The ocean temperature in the southern Barents Sea, along the Kola Section, is another example of the prominent warming at high northern latitudes. The location of the Kola Section is shown in the inlet in Figure *3*, and it probes the temperature of the Atlantic Water flowing northward along the coast of Norway and into the Barents Sea/Arctic Ocean. Averaged over the uppermost 200 m of the water column and along a 220 km long section, the ocean temperature – in this case the temperature at the core of the poleward flowing Atlantic Water – has increased by approximately 0.8^{o}C since the measurements started in year 1900. This is a remarkable warming of the ocean; substantially influencing ecosystems and fisheries in the region.

Arctic amplification will influence all life at high northern latitudes, and it is expected to impose existential challenges to indigenous people (endnote 20).

(1.4f) Global sea surface temperature

Figure *4* shows the development of absolute (actual) sea surface temperature since 1985. Between the period 1985-1989 and 2020-2024, global sea surface temperature has risen by around 0.7^{o}C. There has been a particularly dramatic warming since March 2023, with record high and hitherto unknown monthly temperatures since.

The ocean warms not only at the surface, but also to great depths. The main heating is found in the top 700 m of the water column, but there is also a significant heating down to 2,000 m depth, as well as in the abyss (endnote 21). Warming of the world's oceans plays a key role for the Earth's climate, see the next section.

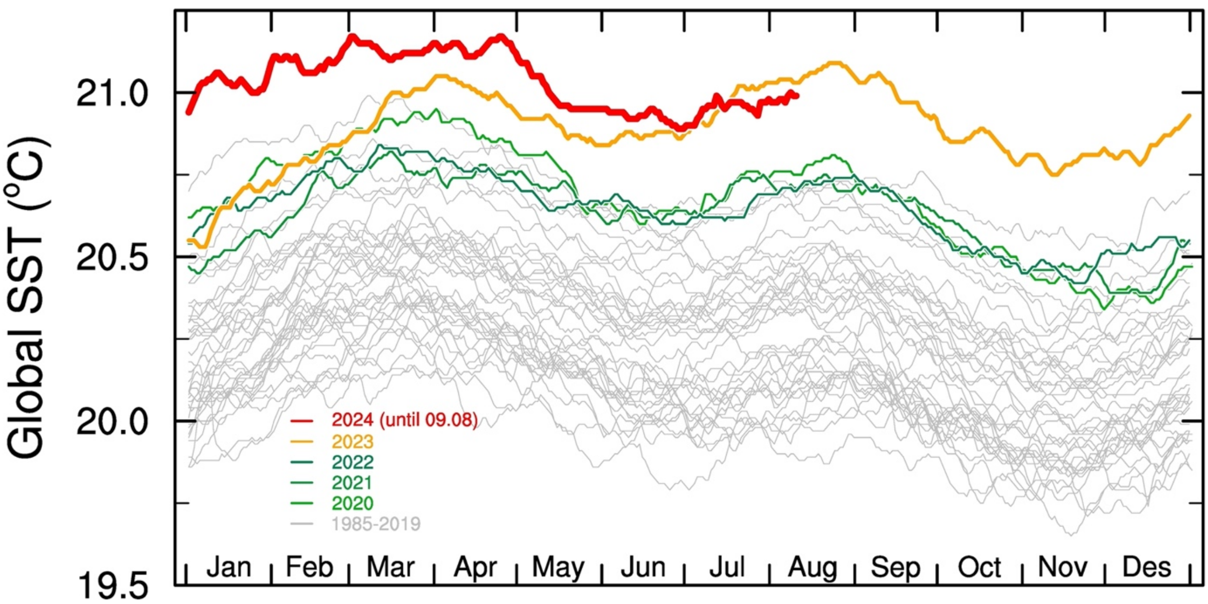

Figure 4. Daily, near global (60^{o} S to 60^{o} N) sea surface temperature (^{o}C) from January 1981 until 9th August 2024. The time series are based on a composite from satellites, ships, buoys, and drifters. Grey curves show the temperature from 1985 to 2019; the coloured curves are for the years 2020-2024. Data from endnote 22.

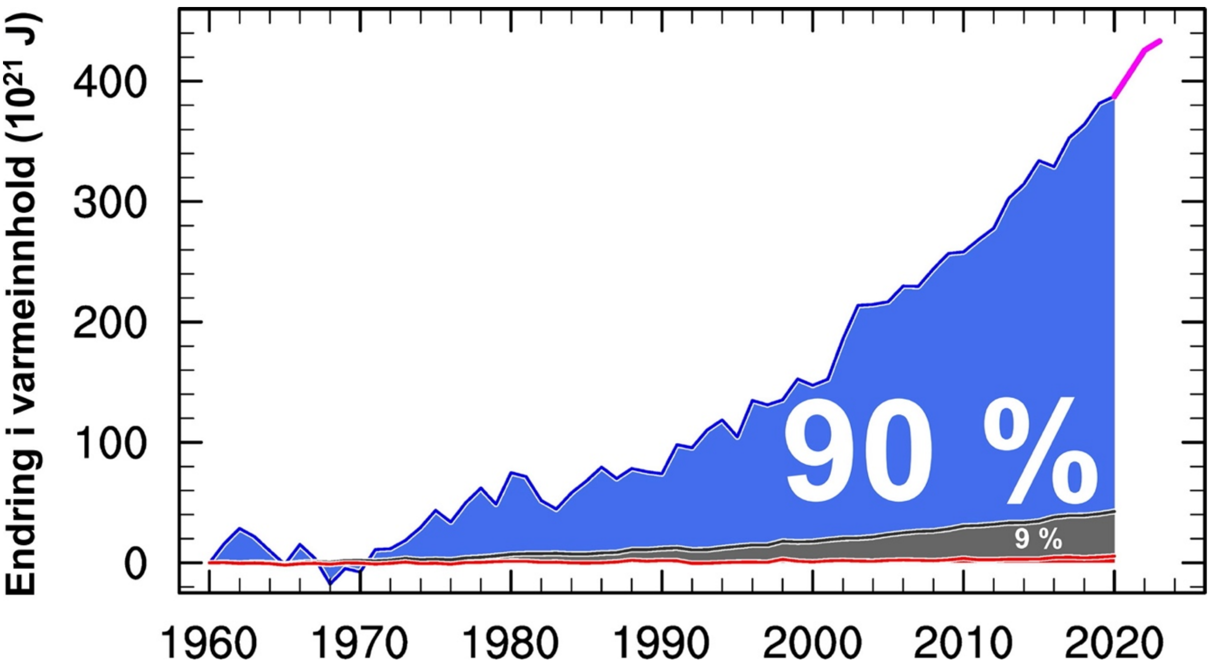

Figure 5. Observation-based change in the Earth's heat content (in 10^{21} Joules) from 1960. Red color corresponds to increased heat in the atmosphere (due to increased air temperature); gray color shows increased heat in bedrock (due to heating of the bedrock) and heat that has gone to melt ice on land and sea; and blue color shows increased heat content in the sea (due to warming of the World's oceans). The purple curve shows changes in the ocean's 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 of ice; while (only) one per cent is due to warming of the atmosphere. Data source in endnote 23.

(1.4g) Ocean heat content / ocean temperature

The single, most profound change in the Earth's climate is found in the ocean, in the form of increase ocean temperature. This is illustrated in Figure 4, displaying changes in the total heat content[2] of the atmosphere, the 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 heating of solid Earth (soil and bedrock) and 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 dominating degree – controlled by the ocean. The warming of the ocean is measured from the surface to the abyss (endnote 24).

(1.4h) CO_2 in air

The atmospheric content of CO_2 reached a new record in 2023 and it is continuing to increase in 2024. 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 25).

[2] Heat content is a measure of thermal energy. As an 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 rise of one degree Celsius in one cubic meter of seawater requires 3,500 more energy than heating one cubic meter of air by one degree.

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

Figure 5 shows the evolution of the atmosphere's CO_2 content since 1850 (blue line), together with the change in global temperature from the Hadley Center in England (red line; this curve is identical to the "HadCRUT" time series in Figure *1*).

The increase in the atmosphere's 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 26).

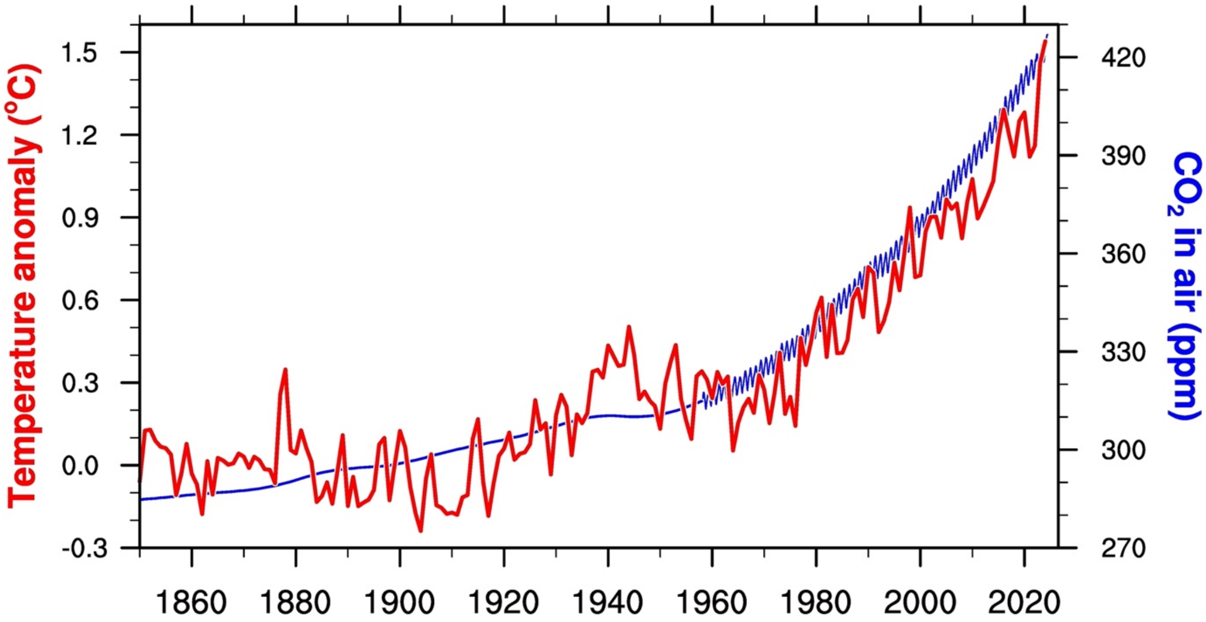

Figure 6. Comparison of CO_2 in air (blue colour; unit is ppm or "parts per million"; 400 ppm corresponds to 0.04 per cent CO_2 in air, last data point is from June 2024), and change in the annual mean global temperature (°C) 1850-2023 (red colour; from the Hadley Centre in England, which is the same curve as the one marked with "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 27.

(1.4i) Record high and accelerating sea level

Figure *7* shows the change in global sea level based on sea gauge (or sea level) measurements from year 1900, and from satellite measurements since 1993. It follows that the 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 mainly caused by melting of the Greenland and Antarctic ice caps and glaciers, and partly due to warmer seas (Figure *8*, and endnote 28).

The possibility of a future sea level several meters higher than at present, with existential consequences for society, food production, access to fresh water, ecosystems, cultural heritage etc., is one of the main arguments for the Paris Agreement's establishment of the 1.5ºC temperature target (endnote 29).

For humanity, global sea level will remain high "forever", i.e., until the next ice age comes, some 50,000 to 100,000 years into the future (endnote 30).

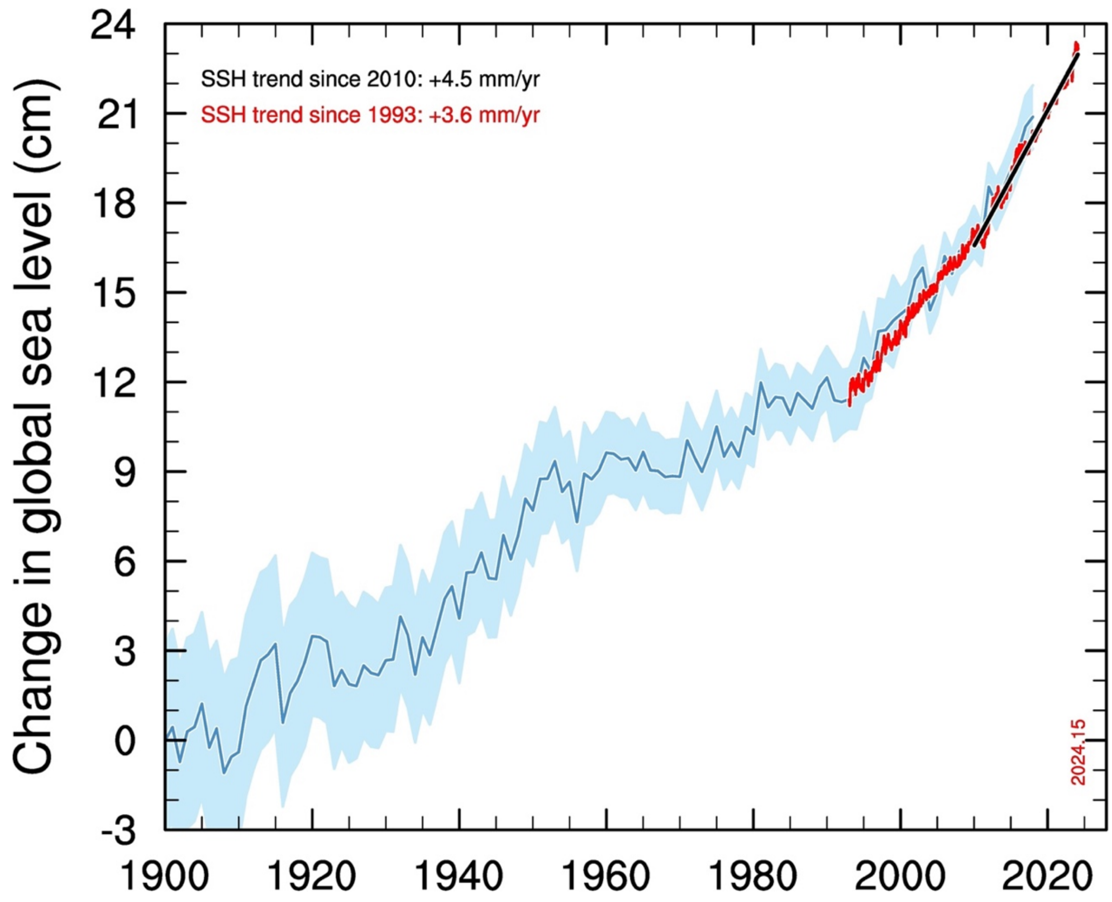

Figure 7. Change in global sea level (in cm) based on sea level gauge measurements along the coasts (blue curve and shading), as well as from satellite (red colour). The increase since 2010 is 4.5 mm/year, corresponding to 45 cm per 100 years if the current change continues. Last data point is from Feb 5, 2024. Data sources in endnote 31.

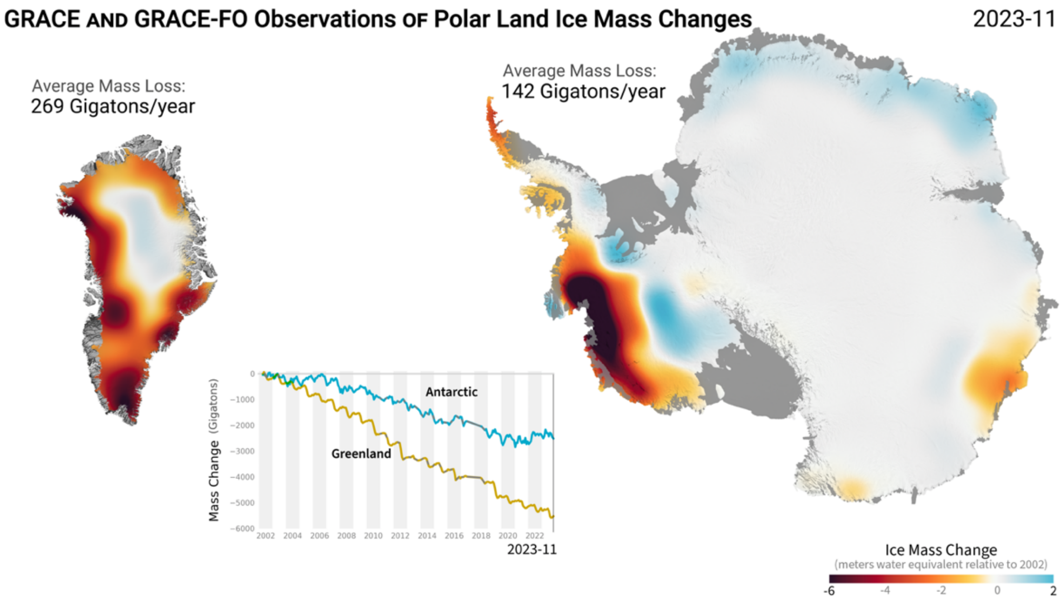

Figure 8. Ice mass changes on Greenland (left) and in Antarctica (right) since 2002, measured by satellites. On the maps, red colours show loss whereas blue colours show accumulation of ice and snow. The time series panel displays the net ice mass change for the two ice caps. Mass changes are given in billion tons of ice. Figure from endnote 32.

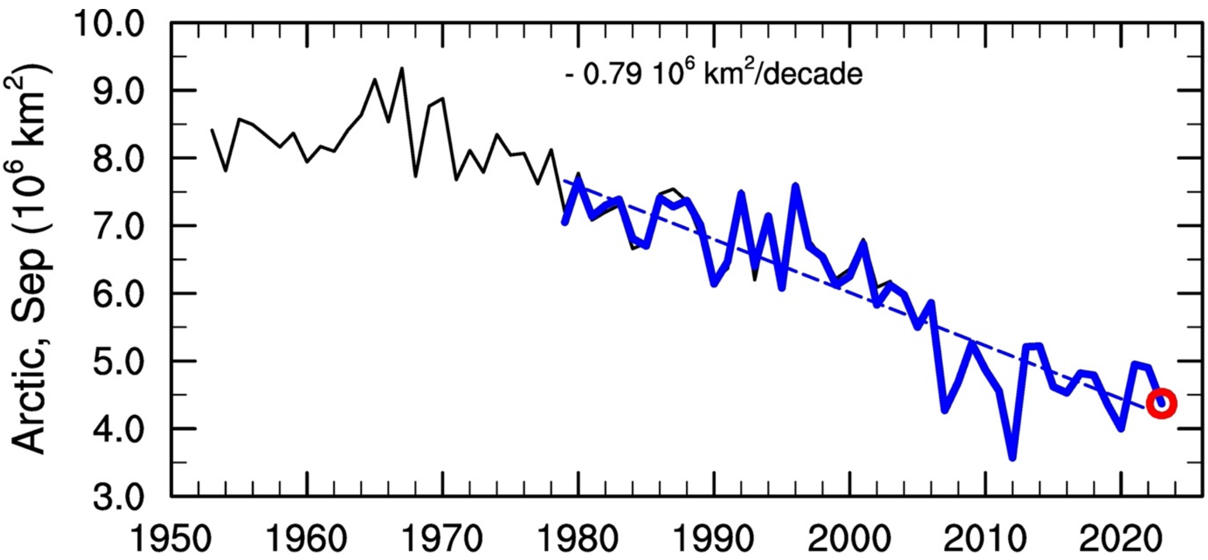

Figure 9. Observed extent (in million km²) of Arctic sea ice in September, with September 2023 in red. Black curve is based on historical write-downs; blue curve from satellite. Data sources in endnote 33.

(1.4j) Reduced 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 lowest extent of sea ice in the Arctic, around half of the ice has disappeared compared to the 1950s, see Figure *9*.

Parallel to the reduced extent of sea ice, the ice is both thinner and younger than the situation a few decades ago (endnote 34).

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 35).

The diminishing extent of the Arctic sea ice contributes to intensified Arctic warming, with direct consequences for indigenous people (endnote 20).

1.5 Change in extreme events

In the following, a brief overview of changes in weather extremes are given.

Figure *10* summarise 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 *11* 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 Figure *10* and Figure *11*, there is a statistically significant increase in extreme temperature and precipitation events. There is also a demonstrable connection between man-made greenhouse gas emissions and extreme temperature and precipitation events.

Both findings are important since uncommon, often disruptive, weather events influence individuals, society and infrastructure, including individual and societal safety, food production, water resources and water quality.

With record high temperatures, there were also a number of extreme weather events in 2023. Many of these events were enhanced by human-caused warming, among others investigated by the academic collaboration World Weather Attribution (endnote 36). This includes prolonged droughts and severe heat waves in North America, in southern and central Europe and in Asia, extensive forest fires in (especially) Canada and extreme rainfall on several continents.

Weather-wise, the world is now in uncharted territory (endnote 37). There are also multiple examples of extreme weather events in 2024 (endnote 38).

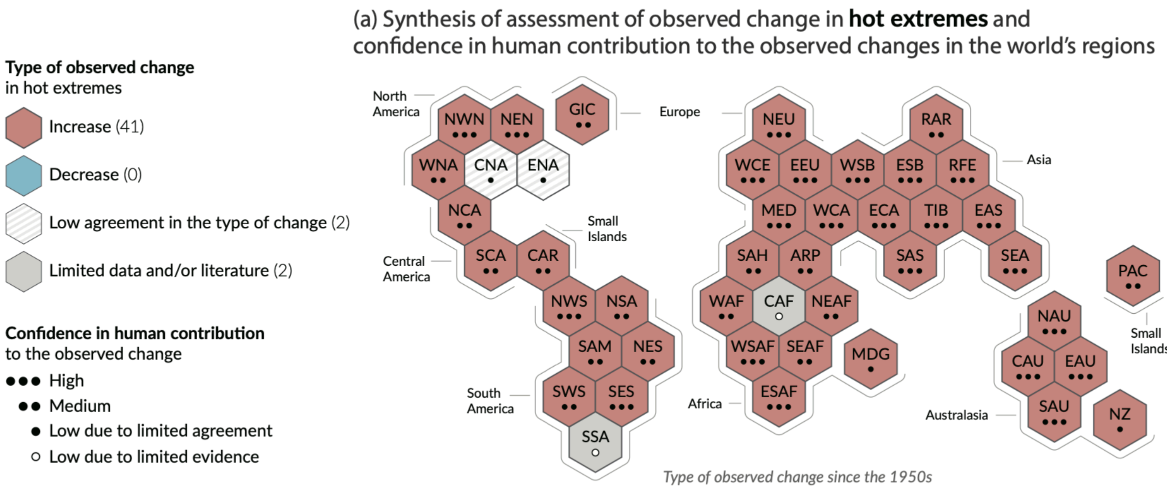

Figure 10. Changes in hot extremes and the confidence in human contribution to the observed changes, divided into sub-continental regions. The cell labelled "NEU" represents Northern Europe. Red colour shows regions with increasing hot extremes; three dots show that there is high certainty linked to the connection between hot extremes and human contributions. Figure from endnote 39.

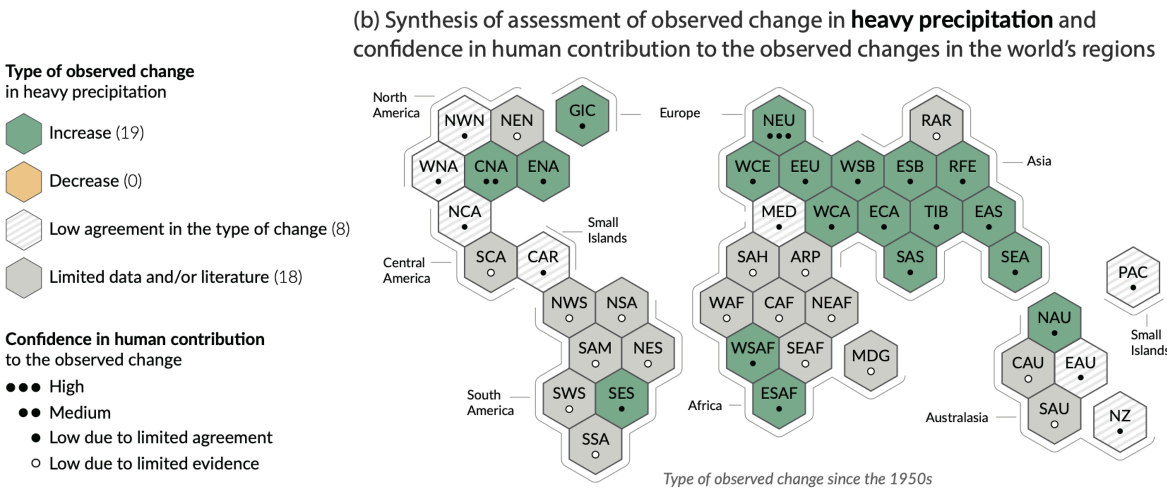

Figure 11. As Figure Figure 10, but for extreme precipitation. For the area of Northern Europe ("NEU"), there is a demonstrable increase in extreme precipitation events, as well as a high degree of certainty that this change is linked to human contributions. Figure from endnote 39.

Extreme weather events took also place in Norway in 2023, with the rainstorm "Hans" causing devastating flooding and landslides as the most severe event. According to Finance Norway, "Hans" caused 7.4 billion NOK damage on buildings and properties (endnote 40). In addition to this, there were substantial damage on municipal and state infrastructures and properties, including roads and railways. For the latter, the Norwegian Government has allocated NOK 1.7 billion NOK for municipal support and to rebuild infrastructure (endnote 41).

1.6 Tipping elements and 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 42). 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 are thawing; or that the boreal forest is dying in the south and moving poleward in the north.

An overview of the most central tipping elements and their possible crossings is shown in Figure *12*. It follows that seven tipping point crossings go from "possible" to "likely" when global warming increases from 1.5°C to 2°C. This illustrates the importance of limiting global temperature rise as much as possible.

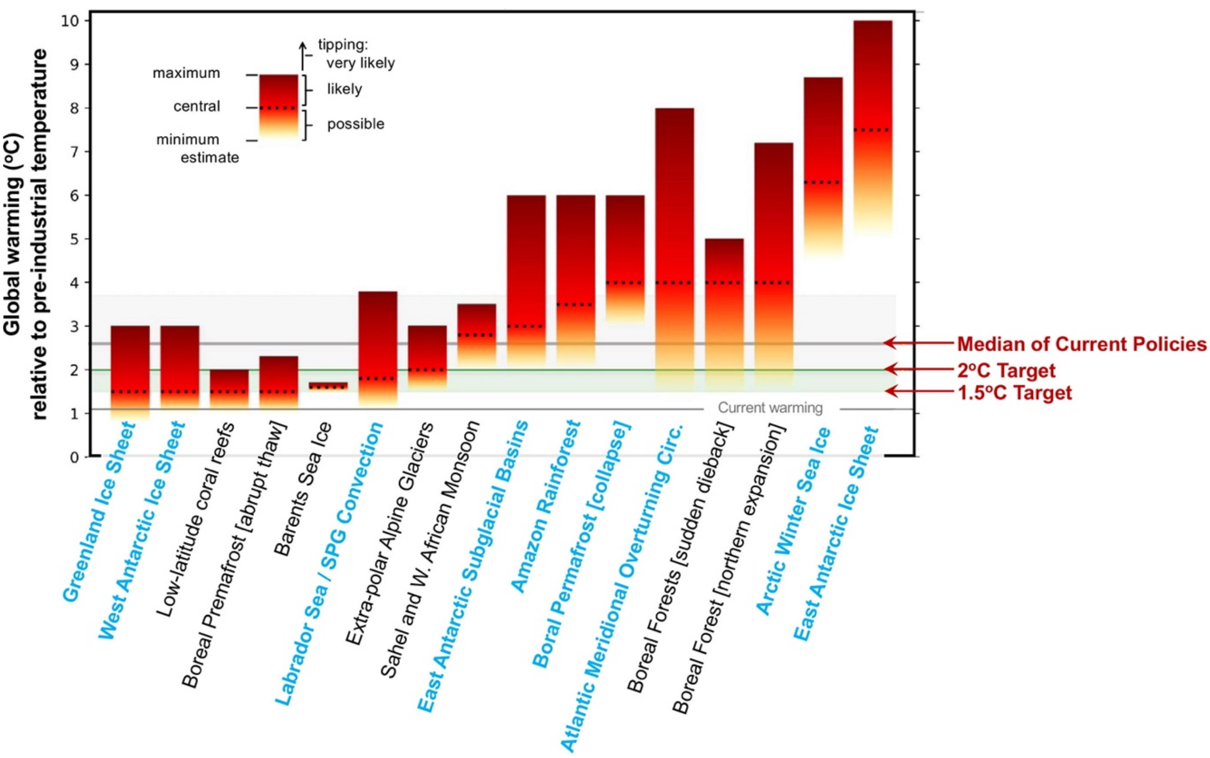

Figure 12. Overview of tipping elements of which nine elements will affect global climate (blue tilted text) and seven other elements with a more local effect (black tilted text). The vertical bars show when the tipping elements can be expected to be activated; black dashed line shows the temperature when the likelihood for crossing tipping points go from possible to likely. Vertical scale shows change in global temperature (°C) since pre-industrial times, with the 1.5°C and 2°C targets shown on the right. "Median of Current Policies" indicate the global temperature in the year 2100 if all countries fulfil their pledges and policies to reduce greenhouse gas emissions. Figure is based on figure 2 in endnote 42.

Of the seven tipping point crossings that may occur as global warming increases from 1.5ºC to 2ºC, five will affect Norway directly. The tipping elements in question are:

- collapse of the ice sheet in West Antarctica (resulting in higher sea level);
- thawing of permafrost (leading to unstable land/mountain slopes, and which can contribute to increased emissions of methane);
- 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 1.5ºC and 2ºC, is rapid loss of ice from 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 43). The reason for this seemingly paradox is that the loss of ice on Greenland will change the Earth's 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, loss of ice in Antarctica will lead to 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 water supplied to the North Atlantic may weaken the Gulf Stream system.

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 (endnote 44). 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 Antarctic 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 level would rise by 7 m, while melting of the Antarctic ice sheet would contribute near 60 m of global sea level rise[3]. Today, both ice sheets contribute to rising sea levels (endnote 45). Should the contributions increase with increasing temperature, the global sea level 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 disintegration of the Greenland and Antarctic ice sheets with the red dashed line until 2100, and the two vertical columns for year 2300, in Figure *13*.

[3] Complete melting of the Greenland and/or Antarctic ice sheets will not occur; but 7 and 60 m indicate the significance for global sea level if only a fraction of the ice sheets melt.

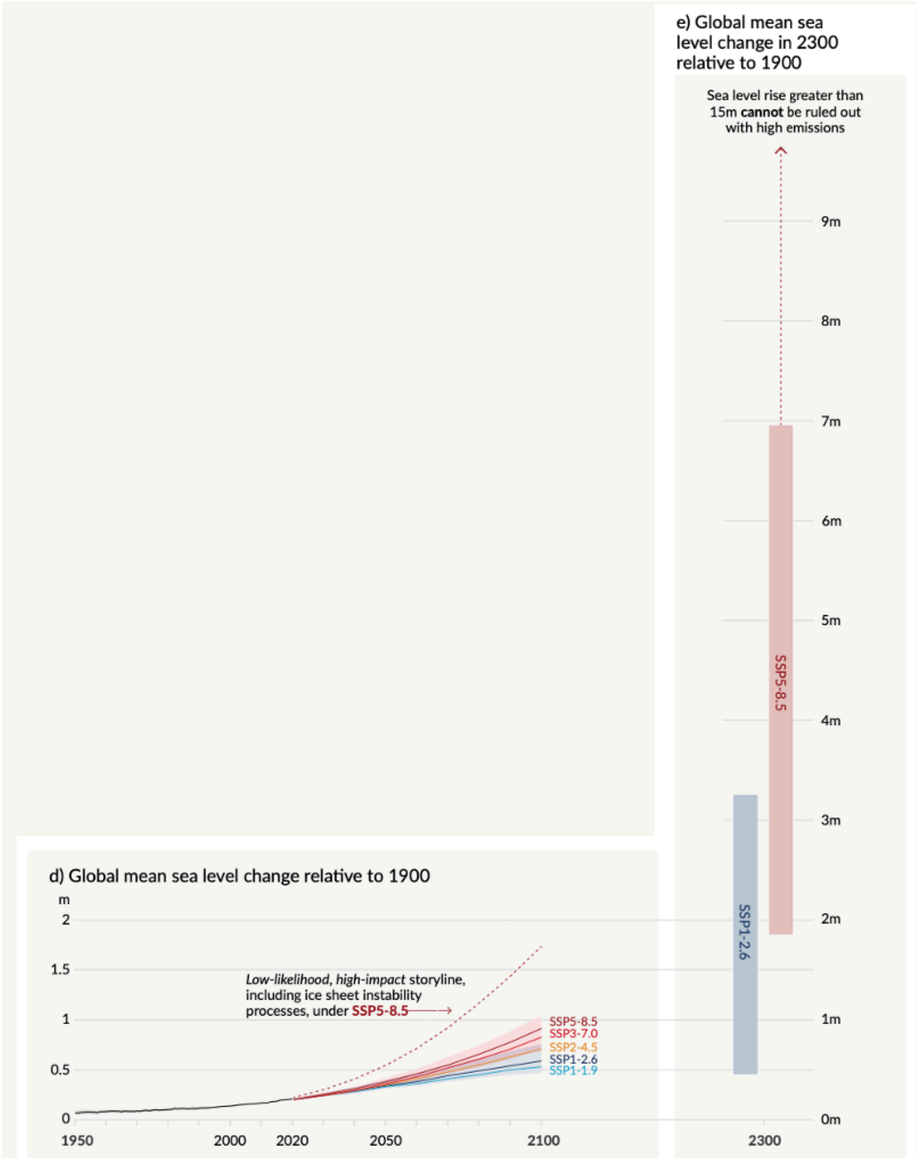

Figure 13. Observed and modelled change in global sea level (m) between 1950 and 2300. The left part of the figure (marked d) shows modelled sea level from 2020 to 2100 based on five different emission scenarios; scenario SSP1-1.9 is in line with the 1.5°C target, while scenario SSP5-8.5 is a so-called business-as-usual scenario (i.e., without reduced greenhouse gas emissions). In this panel, sea level rise due to large and sudden loss of ice from the ice caps is added (stippled line). All sea level changes are relative to the sea level in year 1900. The right part of the figure indicates possible sea level changes in 2300 for a scenario consistent with the 2°C target (blue column) and a business-as-usual scenario (red column). Figure from endnote 46.

While a global sea level rise of between 50 and 80 cm is considered most likely towards the end of the current century (the coloured lines in Figure *13* d), large contributions from the ice sheets in Greenland and/or Antarctica cannot be ruled out (the two dashed lines in Figure *13*).

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 the collapse of the ice in West Antarctica as a result (endnote 47). West Antarctica alone can contribute several, in the range 3-5, meters of global sea level rise.

The Norwegian coast will also be affected by 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 Greenland's 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 the greenhouse gas emissions can delay – and possibly prevent – significant contributions from the ice sheets to global and local (like the Norwegian coast) sea level.

In a recently published report on sea level rise projections along the Norwegian coast (endnote 48), the possibility of rapid sea level rise is described as:

> "For a low-probability but high-impact scenario, where 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 m until 2100. In some places along the coast, especially Stavanger and Bergen, you can experience close to 2 m of sea level rise...".
>
> (Comment: "SSP5-8.5" is an emission scenario with continued high greenhouse gas emissions in this century. "Relative sea level rise" is the sea level rise seen from land, i.e., when land uplift is accounted for).

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) Warming

Firstly, increasing amounts of CO_2 in the atmosphere leads to reduced heat loss from the Earth to space, implying higher temperature on Earth – both in the atmosphere, in the sea and on land – and with it a changing climate. As mentioned above, this connection has been known for more than a hundred years (endnote 49), and it has overwhelming support in the scientific literature, in scientific organizations and in academies worldwide (endnote 50).

(1.8b) Main contribution to man-made warming

Secondly, very large amounts of man-made CO_2 are added to the atmosphere. We must go back two to three million years – i.e. long before the existence of modern man on Earth – to find an atmosphere with corresponding levels of CO_2 (endnote 51). 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 52).

(1.8c) Longevity

Thirdly, around 20 per cent of today's CO_2 emissions will affect the Earth's climate for thousand years or more (endnote 53), 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 extensive and long-lasting climate change. Alternatively, CO_2 must be captured from the atmosphere to an extent that is greater than man-made CO_2 emissions, followed by safe and lang-term storage on Earth, for instance 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 significantly mitigate – less balance – man-made CO_2 emissions (endnote 54).

(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 55). 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 measured throughout the World's oceans (endnote 56).

The consequences of the 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 increasingly difficulties to form shells (endnote 56). Furthermore, corals and calcareous shells and sediments will gradually disintegrate. There are also reasons to expect that fish eggs and larvae will be affected by a reduced pH value (endnote 56). Ocean waters with low water temperatures, such as in the Norwegian and Barents Seas, are more susceptible to acidification than areas with higher water temperatures.

If CO_2 emissions continue at today's level, we may get a stronger acidification of the World's oceans than has been the case during the last 24 million years (endnote 57), with unknown consequences for marine life. Only significant cuts in CO_2 emissions – for example in line with the 1.5°C target – will change this (endnote 58).

2. Can you describe some observed and projected climate changes in Norway?

2.1 Examples of observed and projected changes

Observations from air, land and sea on and in the vicinity of Norway show clear changes in climate, especially for the last 50 years. Compared to similar changes globally and for Norway's neighbouring regions, it can be concluded that these changes cannot be explained as naturally occurring variations in climate.

A review of the climate status for Norway is described in the report Climate in Norway 2100, published in 2015 (endnote 96; a new version of this report will be published in 2025). In addition, a review of sea level rise along the Norwegian coast has recently been published, see endnote 46.

A selection of examples of key climate parameters for Norway – and changes to these – are provided in Figure *14* to Figure *24*, and briefly elaborated below:

Average temperature Norway, Figure *14:*

The annual average temperature has increased by 1.2ºC over the last 100 years, and by 1.9ºC for the last 50 years. The temperature increase for Norway is thus comparable to the rate of global warming[4]. There is an increase in temperature for all months of the year, this holds for both the last 100 and 50 years trends.

Average precipitation Norway, Figure *15:*

Annual average precipitation has increased by 21 per cent in the last 100 years, and by 16 per cent in the last 50 years. There is 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 events have likely increased even more, although this is hard to assess due to limited number of high temporal and spatial observations (endnote 96).

Temperature development Oslo, Figure *16:*

Left panel shows measured change in air temperature in Oslo for the period 1837-2023. For Oslo, the temperature has increased by 1.5ºC during the last 100 years, and by 1.8ºC in the last 50 years.

The right panel in Figure *16* shows a possible temperature development in Oslo if the global temperature rises by 1.4ºC in this century (which is a moderate and reasonable estimate). The main point of this figure is that the future temperature in Oslo (as elsewhere in Norway) will be significantly different from the temperature

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[4] Comparable temperature rise globally and for Norway does not violate the fact that high northern latitudes warm much faster than the global mean, see Figure *2*. The reason for this is that almost the entire of Norway's coast is exposed to the open ocean, and that the sea warms up more slowly than land.

that has been observed – and thus experienced – since the measurements started nearly 200 years ago.

Temperature development Svalbard, Figure *17:*

On Svalbard, the annual average temperature has increased by 3.2ºC during the last 100 years, and by as much as 5.2ºC in the last 50 years. As for Oslo, we can expect a significantly changed temperature (and climate) on Svalbard in this century (right panel).

Snow depth, Eastern Norway, Figure *18:*

Figure *18* shows the snow depth for the months March, April and May at the measuring station Bjørnholt 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, 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 averaged April snow depth at Bjørnholt is 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 BSS and BSSE will reinforce 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 threshold for (good) skiing conditions, Figure *19* shows that the number of "skiing days" has decreased by 50 days since 1900; from around five months a year 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 freezing temperatures. This means that mountain regions can generally be expected to get more snow with global warming (as long as the temperature remains below freezing temperature), while lower altitude areas get less snow. Bjørnholt (Figure *18* and Figure *19*), and all coastal regions in Norway, are examples of the latter.

Number of days with snow, Norway, Figure *20:*

Change in the number of days with snow from measuring stations distributed over Norway for the last 100 years is shown in Figure 23. Green circles with black outlines show localities 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. The greenhouse gas emissions from BSS and BSSE will reinforce this change.

Geohazards:

With rising temperatures and increased amounts of precipitation in the form of rain or snow, increasingly greater challenges are expected with rock, soil and snow avalanches and rockfalls on steep slopes, as well as in the mountains. This is a recurring challenge in the Alps (endnote 59). Similar changes apply – and are expected to increase with time – in Norway (endnote 60). The greenhouse gas emissions from BSS and BSSE will reinforce this development.

Sea level change relative to land along the Norwegian coast, Figure *21:*

For all biotopes, ecosystems, infrastructure and activities, relative sea level, i.e., sea level seen from land, is the relevant quantity to look at. For Norway, parts of the land have an uplift as the result of the massive ice cap sitting over Fennoscandia during the last ice age, pressing the Earth's crust down. After the disappearance of the Fennoscandian ice sheet, the crust moves upwards, and this process is still ongoing. Vertical land uplift is largest 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 *21*.

Since land uplift is constant while sea level rise is accelerating – and will continue to increase for thousands of years due to man-made climate change (endnote 61) – 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, if it were to collapse (see section on tipping elements).

Table *1* lists some of the main results from a recently published report on future sea level change along the Norwegian coast (endnote 48). Five emission scenarios are considered. Of these scenarios, scenario SSP3-7.0 yields a warming of 2.7°C towards the end of this century, corresponding to the warming expected based on current greenhouse gas emissions and nationally agreed emissions pledges (endnote 62).

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 western coast of Norway is due to different degrees of land uplift.

With a 95 per cent 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 will add to the 95 per cent 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.

The greenhouse gas emissions from BSS and BSSE will contribute to future sea level rise globally, as well as along the Norwegian coast. It cannot be ruled out that these emissions may contribute to activation of a tipping element, like collapse of the West Antarctic ice sheet.

Risk of rot damage, Figure *22 and* Figure *23:*

With increasing temperature, increased humidity and increased rainfall, the risk of rot damages increases for all infrastructure built in wood and which is exposed to the weather, be it housing, cultural monuments, etc. For today's climate, the rot problem is greatest along Norway's western coastline (Figure *22*, left). In a warmer and wetter climate, today's most rot-prone areas will expand inland from the coast and to higher elevations (Figure *22*, right).

For a "business-as-usual" scenario, it is estimated that a high rot risk increases from today's approximately 600,000 buildings (out of a total of 3.8 million buildings in Norway) to approximately 2.4 million buildings (Figure *23*).

Even if a "business-as-usual" scenario has a warming well above the 2°C target, the Norwegian Environment Agency expects the risk of rot damage to increase sharply in this century (endnote 63). Increased greenhouse gas emissions will increase the rot problem.

Marine heat waves, Figure *24:*

Similarly to heat waves on land, there are heat waves in sea. As a result of global warming, marine heat waves occur more often and with more intensity than before (endnote 64). In the extreme, a marine heat wave can disturb the marine ecosystem and it can be detrimental for fish (endnote 65). For the Norwegian waters, the frequency and duration of marine heat waves have increased, particularly in the Barents Sea. This is as expected due to the strong warming in the Barents Sea, see Figure *3*.

For the period 1982 to 2020, more than half of all marine heat wave days have occurred in the last decade (endnote 65). Increased greenhouse gas emissions will increase the number and intensity of marine heat waves globally and off Norway.

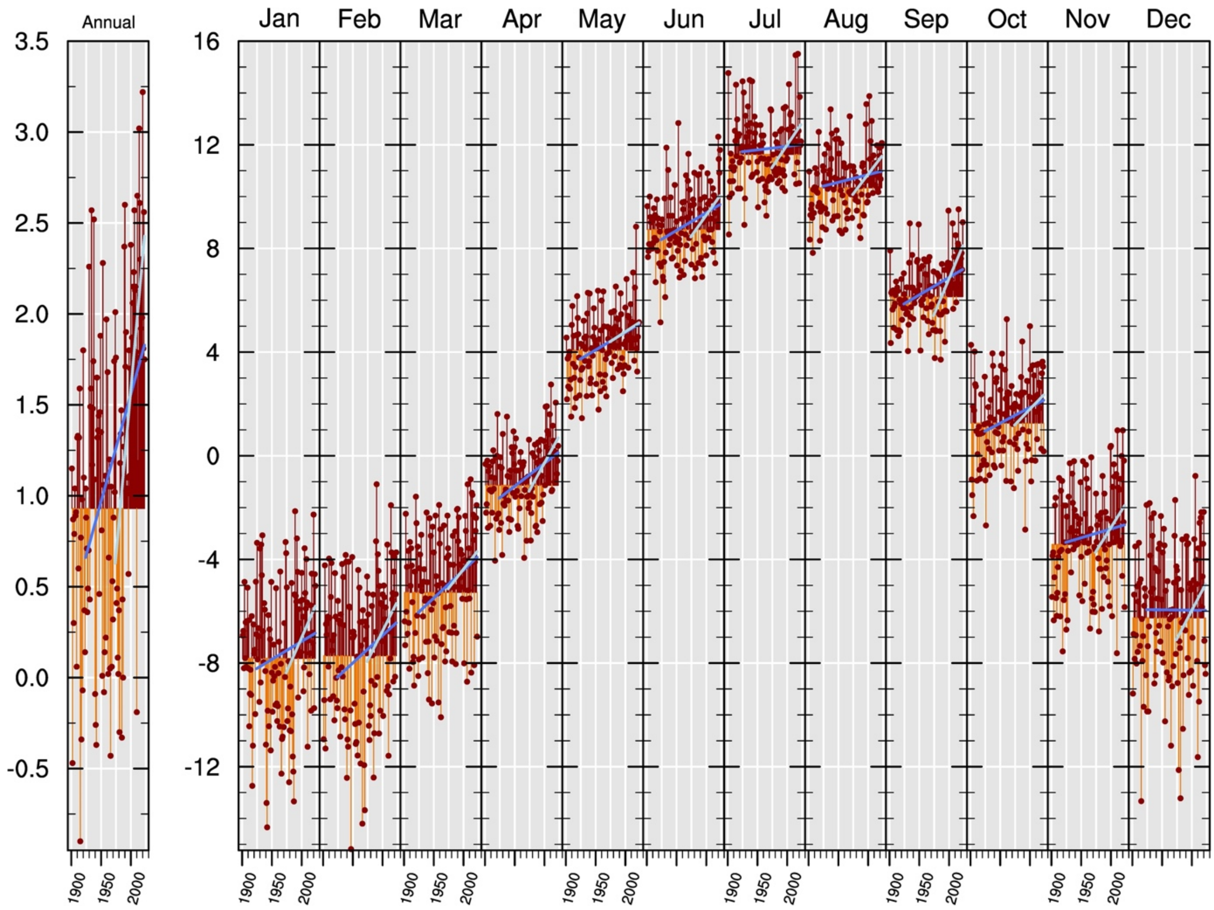

Figure 14. Observation-based annual temperature (left) and monthly temperature (panels on the right) for Norway since January 1900. Mean temperature for the last century is shown with transition between orange and red colours; trend for the last 100 years is shown with a dark blue line and trend for the last 50 years is shown with a light blue line. Data in endnote 66.

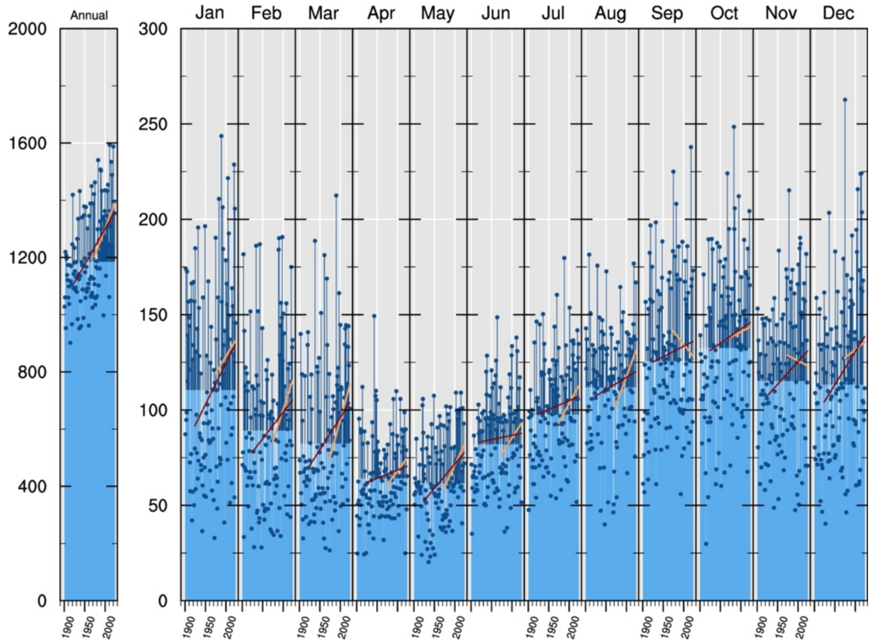

Figure 15. Observation-based annual precipitation (left) and monthly precipitation (panels on the right) for Norway since January 1900. Mean precipitation for the last century is shown as the transition between light and dark blue colours; trend for the last 100 years is shown with a red line and trend for the last 50 years is shown with a yellow line. Data in endnote 66.

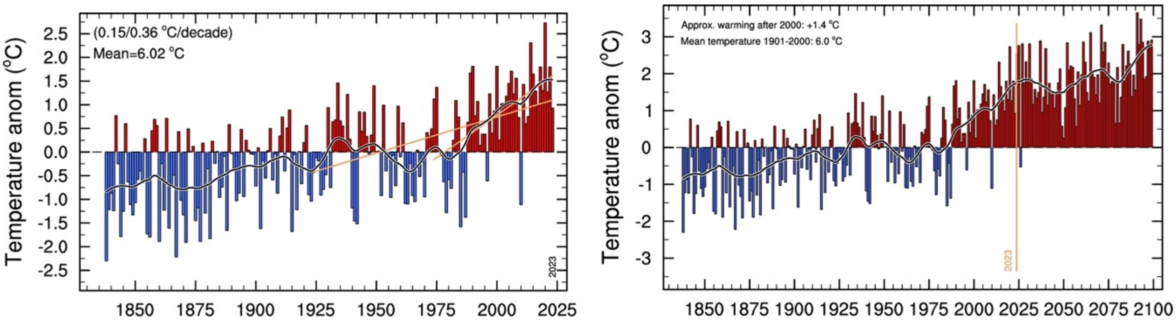

Figure 16. Left: Observed annual mean temperature change for Oslo for 1837-2023. Zero value equals the average temperature for the last century. The observed temperature increase over the last 100 years is 1.5ºC; for the last 50 years it is 1.8ºC. Right: As left until year 2023, but with an assumed warming of 1.4ºC in this century and with a random year-to-year variation based on observed variations during the last 100 years. Data source in endnote 66; temperature projection by H. Drange.

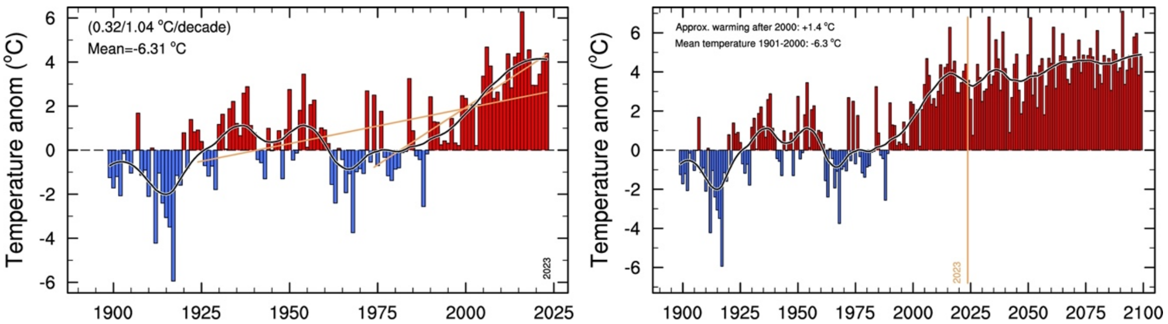

Figure 17. As Figure 16 , but for Svalbard (78º N) since 1899. Observed temperature increase over the last 100 years is 3.2ºC; for the last 50 years the temperature increase is 5.2ºC.

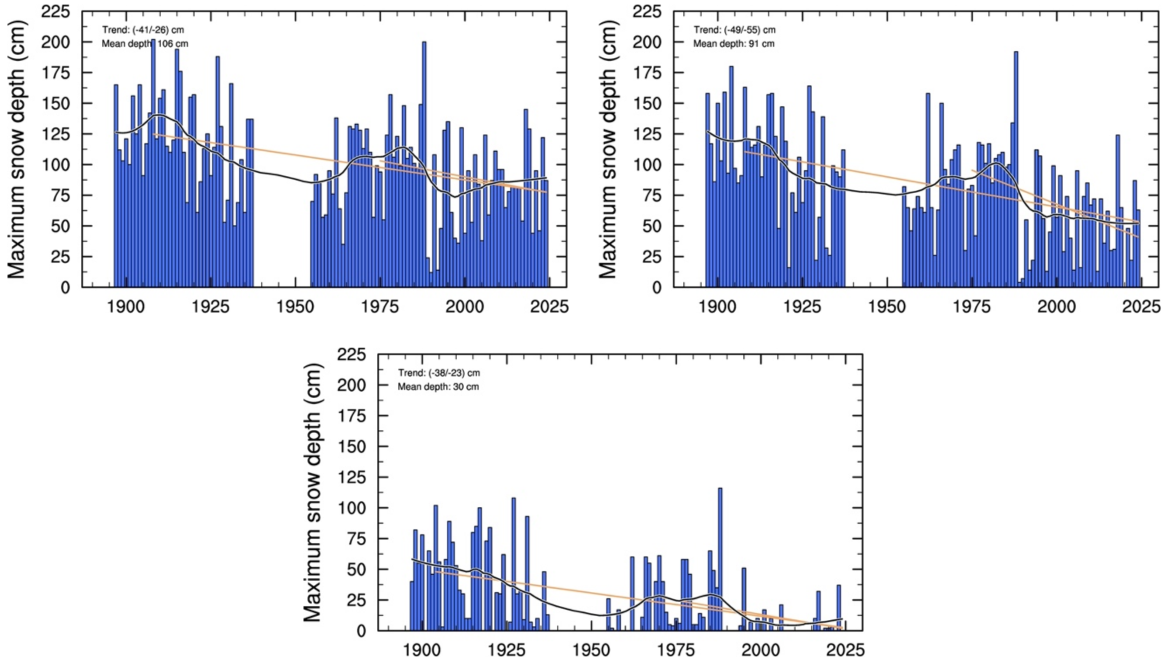

Figure 18. Maximum measured snow depth (cm) at Bjørnholt in Nordmarka, Oslo (360 m above sea level) for the months March (upper, left panel), April (upper, right panel) and May (lower panel) for the period 1897-2024. Trend values (cm) show changes in maximum measured snow depth for the last 100 and 50 years, respectively. "Mean depth" is the average maximum snow depth for the last century (1901-2000). Data in endnote 66.

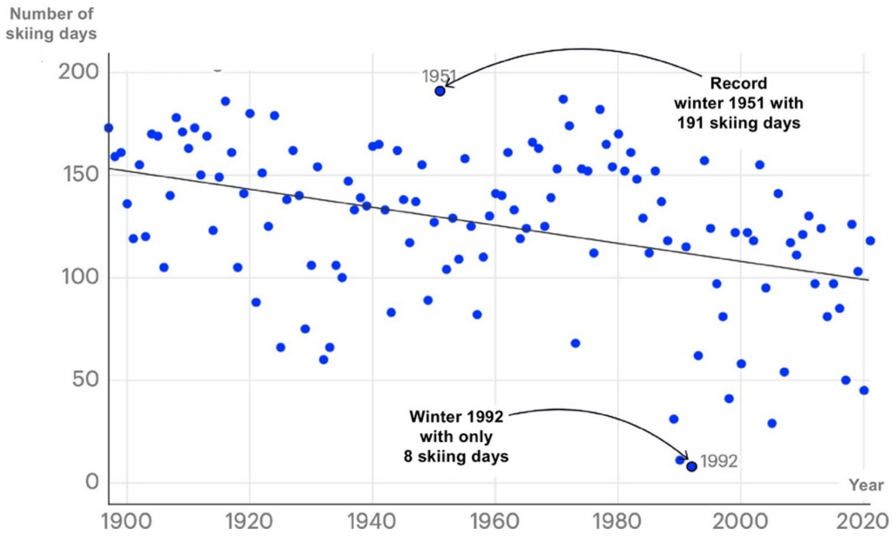

Figure 19. Number of skiing days, here defined as days with more than 25 cm of snow, at Bjørnholt/Nordmarka, Oslo. Data in endnote 67.

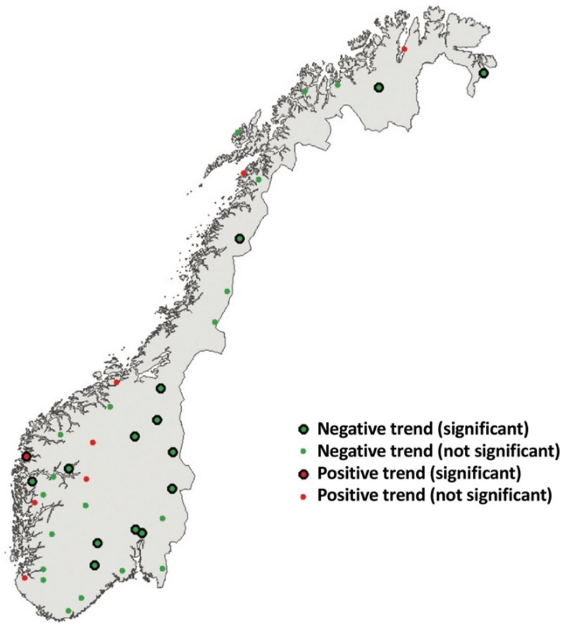

Figure 20. Change in the number of days with snow at some long-term monitoring stations in Norway. Green circles with black highlighting show localities where there has been a significant (statistically certain) decrease in the number of days with snow in the last (approximately) 100 years. Data in endnote 68.

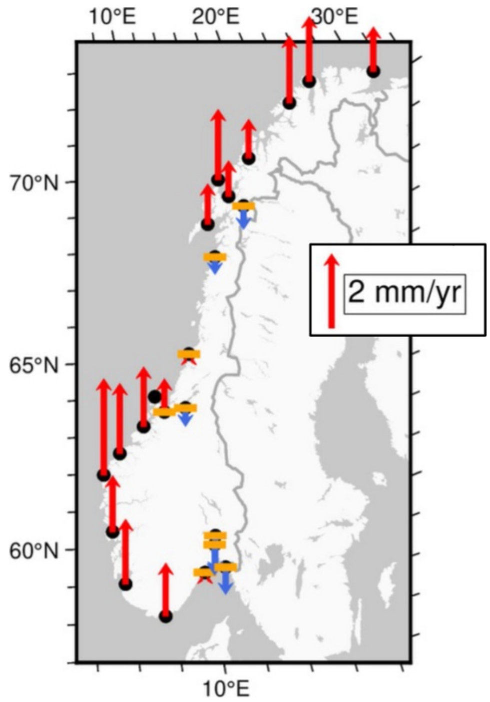

Figure 21. Observed change in sea level relative to land (mm/year) along the Norwegian coast for the period 1993-2022. Red arrows show rising sea level relative to land; blue arrows that sea level falls relative to land. Source endnote 69.

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

Table 1. 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 changes in the range from five to 95 per cent likelihood, with values given for the period 2081-2100 relative to 1995-2014. The four emission scenarios give a global warming of 1.4°C, 1.8°C, 2.7°C, 3.6°C, and 4.4°C, respectively. The two columns on the right represent scenarios with rapid melting of the ice caps in Greenland and Antarctica. Data in endnote 48.

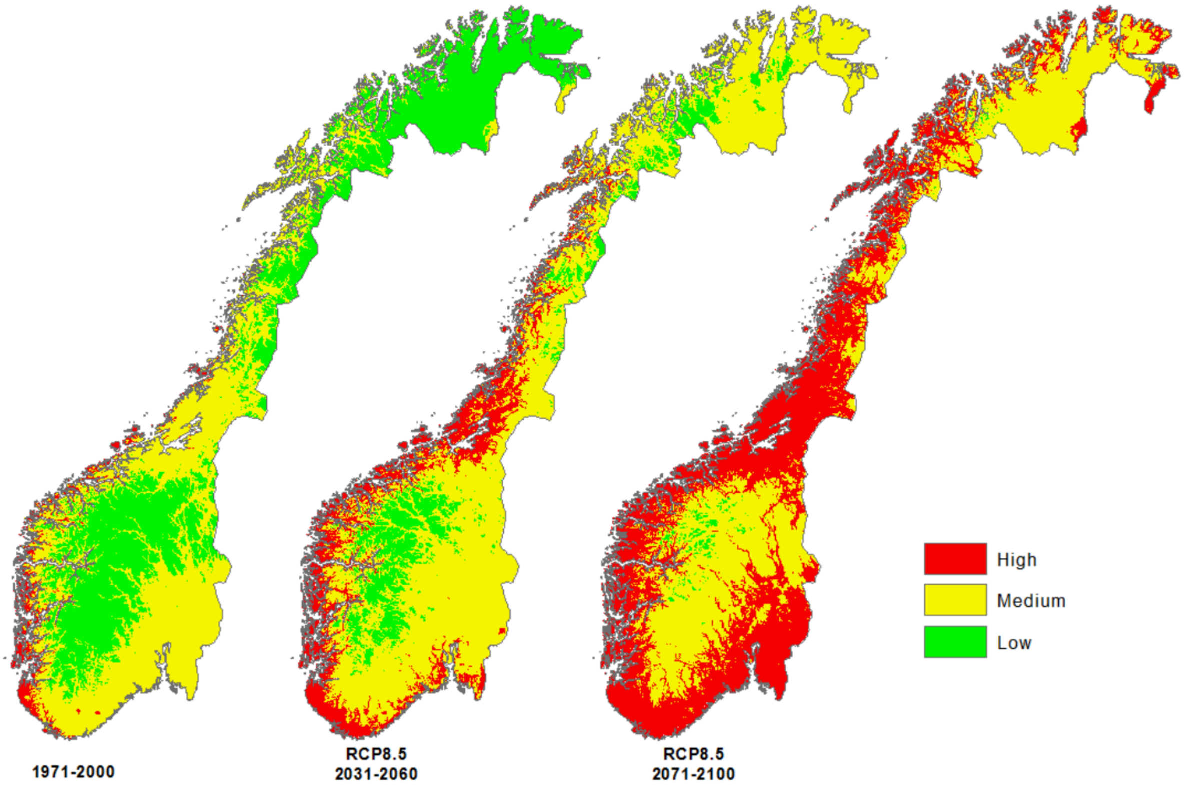

Figure 22. Risk for wet rot in buildings in Norway for "present" climate (left panel) and for two future time periods, for 2013-2060 (mid panel) and for 2071-2100 (right panel). The colouring shows areas with a high, moderate and low rot risk in red, yellow and green, respectively. As a future scenario, a "business-as-usual" is used. Source, see endnote 70.

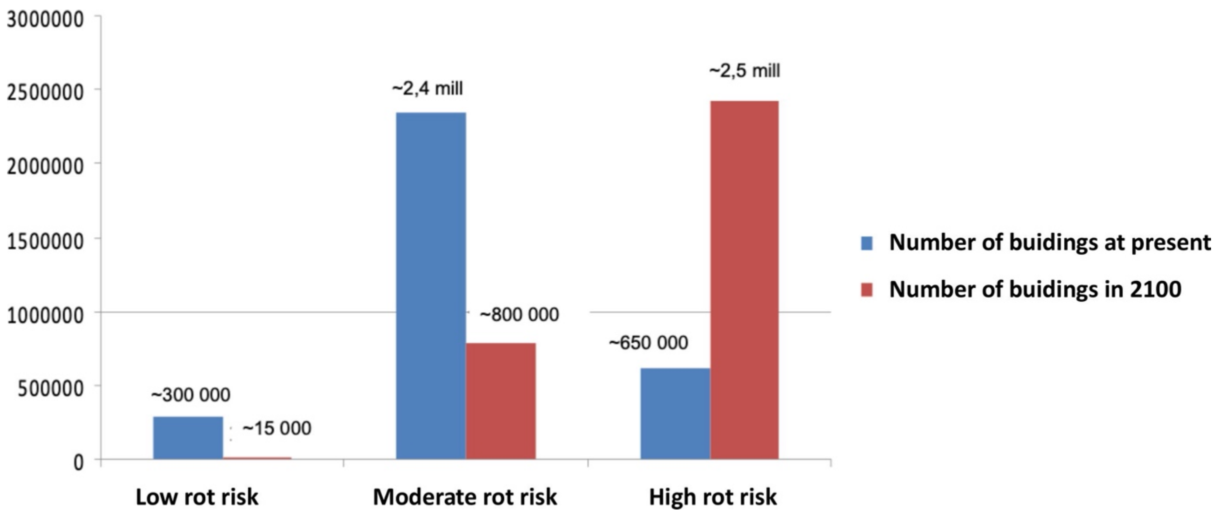

Figure 23. Number of buildings on mainland Norway with low, moderate and high rot risk for today's climate (blue colour) and for a climate in 2100 based on a "business-as-usual" scenario (red colour). Only existing buildings are included. Source, see endnote 71.

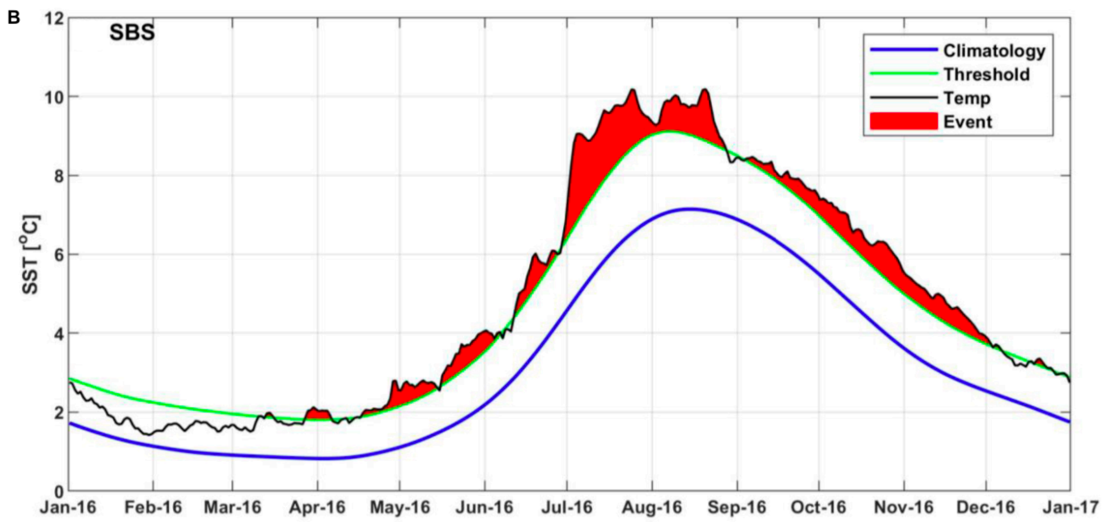

Figure 24. Seasonal change of Southern Barents Sea surface temperature (°C) temperature. Blue curve shows the average (climatological) temperature variation throughout the year; while the black curve shows the actual sea surface temperature in 2016. Green curve is a threshold value for the occurrence of marine heat waves in the area, with red colours marking the presence of marine heat waves. Figure, see endnote 72.

2.2 Registered climate-related insurance claims and payouts in Norway

Figure *25* 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 *25*. Water intrusion, frost and lightning damage adds to this, yielding a total of NOK 7.4 billion (endnote 73). The single, major event in 2023 was the extreme weather event "Hans" on August 7-9, influencing large parts of Eastern Norway with significant flood and stormwater damage (endnote 74).

In addition to the above, there are uninsured values 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 75). The total cost of weather and natural damage in 2023 is therefore around NOK 9 billion.

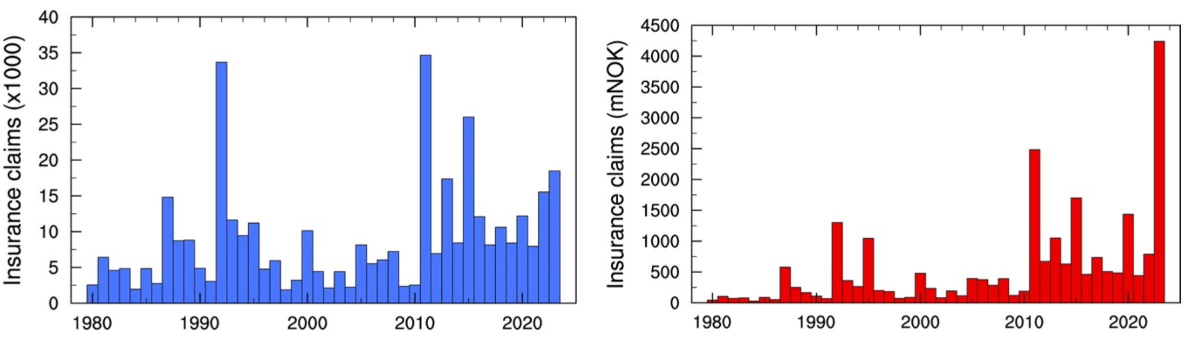

Figure 25. Total number of registered insurance claims from storms, storm surges, floods and landslides (left) and the associated insurance pay-outs (in millions of NOK; right) in Norway for the period 1980-2023. Data from endnote 76.

3. What was the World's remaining carbon budget to limit warming to 1.5°C and 2°C with 50, 67 and 83 percent likelihood per 2023?

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 for keeping 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 77).

Science shows that future temperature rise can be estimated based on the sum of future global emissions of CO_2 (endnote 78). The most recent estimates of future CO_2 emissions in line with a mean warming of 1.5°C and 2°C are given in Table *2*.

As is discussed in the subsections below, there is a certain possibility that a given carbon budget may lead to a stronger warming than that indicated by the assigned temperature target; it all depends on whether the likelihood for the warming is 50 per cent, 83 percent, 90 percent or higher.

Warming target (°C)	**Likelihood**		
	50 %	**67 %**	**83 %**
	Global emissions from 2024 in in Gt-CO_2 (Gt-CO_2 is billion tons CO_2)		
1.5	200	150	100
2.0	1100	900	750
	Number of years with 2023-emissions (global emissions in 2023 is (ca.) 37 Gt-CO_2, from endnote 79)		
1.5	5.4	4.1	2.7
2.0	29.7	24.3	20.3

Table 2. Overview of future (starting from January 2024) CO_2 emissions compatible with the 1.5°C and 2°C warming targets with an assumed likelihood of respectively 50, 67 and 83 per cent. See endnote 80 for the source for the compatible carbon budgets.

3.1.1 The 1.5°C target

With 50 per cent likelihood that the global temperature rise does not exceed 1.5°C, the total global emissions, starting from January 2024, are limited to 200 billion tonnes of CO_2 (Table *2*). This corresponds to about 5 years with current (2023) emissions, and zero emissions thereafter.

If the likelihood of limiting global warming by 1.5°C is increased to 67 per cent (implying 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. With an 87 per cent likelihood (corresponding to a five-sixths probability), the carbon budget is 100 billion tonnes CO_2, corresponding to 3 years of current emissions.

Given the global and regional consequences of a changing climate, an 83 per cent likelihood for a given temperature target is far from being a strict criterion. In the 2018 IPCC Special

Report *Global warming of 1.5°C* (endnote 81), it is summarised that even emission scenarios that are constructed to give a mean warming slightly below 1.5°C, has a 5 per cent probability of exceeding 2°C, and a 1 per cent probability of exceeding 2.5°C. For 1.5°C emission scenarios including a temporally limited temperature overshoot, there is a 10 per cent probability of exceeding 2°C, and a 1 per cent probability of exceeding 2.5°C.

3.1.2 The 2°C target

From Table *2*, limiting global warming to 2°C with a likelihood of 50 per cent implies that today's CO_2 emissions can continue for 30 years. With an 83 per cent likelihood, today's emissions can continue for 20 years.

Stricter criteria – as summarised in the 2018 IPCC Special Report *Global warming of 1.5°C* (endnote 81) – state that emission scenarios resulting in a mean warming slightly below 2°C, have a 26 per cent probability of exceeding 2°C, and a 6 per cent probability of exceeding 2.5°C. For emission scenarios giving a mean warming slightly above 2°C, there is a 40 per cent probability of exceeding 2°C, and a 13 per cent probability of exceeding 2.5°C.

3.1.3 Comment regarding the 1.5 °C and 2°C targets

Based on the 2018 IPCC Special Report (endnote 81), only emission scenarios that are constructed for the 1.5°C target, without or with only very small temperature overshoots, can be viewed as a safeguard for keeping global warming to less than 2°C. For emission budgets exceeding the 1.5°C target, there is a certain degree of likelihood of a warming around or in excess of 2°C.

4. What is the magnitude of the emissions embedded in the Barents Sea South and Barents Sea South-East resource estimates (medium and maximum) compared to Norway's annual territorial emissions?

4.1 Magnitude of the Barents Sea resources, expressed as greenhouse gas emissions

Two groups of Barents Sea South-East emission scenarios are used in this report.

(a) An early production scenario for the Barents Sea South-East region, hereafter Barents Sea South-East 2020 or BSSE2020, assumed a low and high production scenario of 106.9 and 388 Mt-CO_2, respectively.

In this report, carbon dioxide equivalents, or CO_{2e} for short, are used to quantify the climate effect of greenhouse gas emissions. CO_{2e} represents the greenhouse gas forcing that various greenhouse gases would have if they all were turned into the form of CO_2. Consequently, the low and high BSSE production scenarios are presented as 106.9 Mt-CO_{2e} and 388 Mt-CO_{2e} in Table *3*.

(b) An updated resource estimate, based on geological surveys, was presented in St. Meld. 36 (2012-2013), p. 6 (endnote 82). These resource estimates were considerably higher than the BSSE2020 production scenarios mentioned above.

Two values are representative for the resource estimates expressed in terms of CO_{2e}-emissions, one median value and one maximum value. For the Barents Sea South region (abbreviated BSS), this gives the emission scenarios BSS-Median and BSS-Max.

Likewise, for the Barents Sea South-East region (abbreviated BSSE), the corresponding emission scenarios are named BSSE-Median and BSSE-Max.

Values for the various emission scenarios are listed in Table *3*. In addition, the sum of the Median and Max resource scenarios for BSS and BSSE are also provided (named Sum-Median and Sum-Max).

Emission scenario	Emissions in Mt-CO_{2e}	Years relative to Norway's 2023-emission of 46.6 Mt-CO_{2e}
BSSE2020-Low	106.9	2
BSSE2020-High	388	8
BSS-Median	5184	112
BSS-Max	6336	137
BSSE-Median	722	16
BSSE-Max	1627	35
Sum-Median	5906	127
Sum-Max	7963	172

Table 3. First and second column: Overview of the greenhouse gas emission scenarios and emissions (in Mt-CO_{2e}) discussed. The two uppermost rows are based on preliminary low and high production scenarios for the Barents Sea South-East region, labelled BSSE2020-Low and BSSE2020-High. The following rows are emissions from updated resource estimates from Barents Sea South (BSS) and Barents Sea South-East (BSSE), each with a median and high scenario. The sum of the median and high scenarios for BSS and BSSE, labelled Sum-Median and Sum-Max, are also given.

Third column: The magnitude of the different emission scenarios relative to Norway's domestic 2023 emissions of 46.6 Mt-CO_{2e} (endnote 83). For instance, the maximum scenario for Barents Sea South (BSS-Max) of 6336 Mt-CO_{2e} corresponds to 137 years of Norway's domestic 2023 emission.

4.2 Magnitude of Barents Sea South and the Barents Sea South-East resources compared to Norway's domestic 2023 emissions

Norway's domestic greenhouse gas emission in 2023 was 46.6 Mt-CO_{2e} (Figure *26*, endnote 86). Thus, the combined median value emissions from BSS and BSSE corresponds to 127 years of Norway's domestic 2023-emissions (Table 3, right column).

For the maximum value emissions, the corresponding sum of BSS and BSSE resources corresponds to 172 years of Norway's domestic 2023-emissions.

The emissions for the early production scenario for the Barents Sea South-East region, BSSE2020-High, corresponds to 8 years of Norway's domestic 2023-emissions.

4.2.1 Summary

The emissions related to the updated resource estimates for BSS and BSSE are substantial compared to Norway's domestic annual emissions; exceeding the latter with a factor between 130 and 170.

The emissions embedded in the early production scenario for the BSSE is much more modest but are still a factor 2 to 8 higher than Norway's domestic 2023-emissions.

4.3 Overview of Norway's domestic 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 *26*.

It follows that Norway's domestic CO_2 emissions have increased by 8 per cent between 1990 and 2023, while emissions of all other greenhouse gases (such as sulphur components, nitrogen components and methane) have been reduced by 49 per cent over the same period. The reason for the latter is mainly closure/relocation of heavy industry (such as magnesium production), and significantly reduced emissions from aluminium and saltpetre production (endnote 84).

Between 1990 and 2023, Norway's total greenhouse gas emissions are reduced by 9 per cent (Figure *26*), with a 2023-emission of 46.6 Mt-CO_{2e} (endnote 78). For comparison, the total greenhouse gas emissions from the EU-27 countries have been reduced by 32 per cent between 1990 and 2022 (endnote 85).

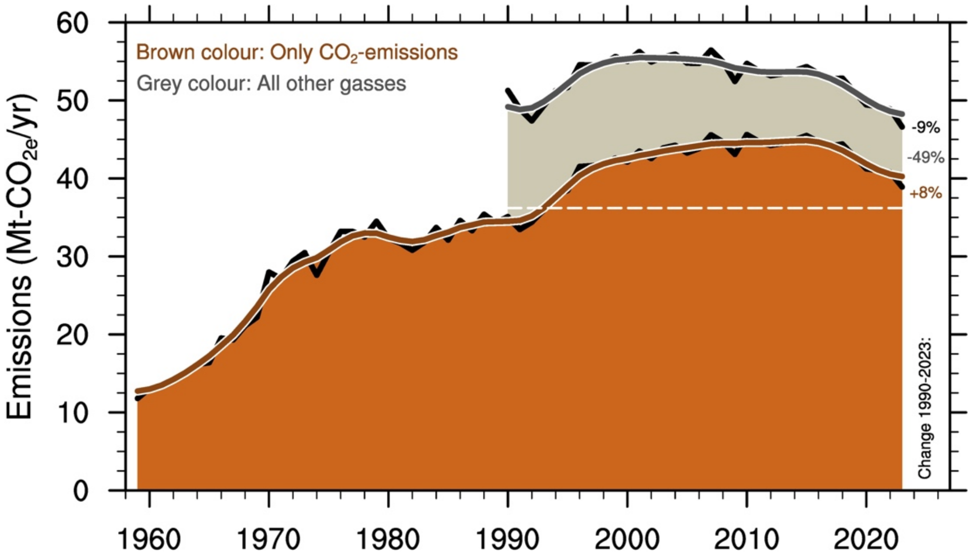

Figure 26. Annual domestic CO_2 emissions from Norway since 1958 (brown colour), and for all other greenhouse gas emissions since 1990 (grey colour). The per centage change in emissions for the period 1990 to 2023 is shown on the right of the figure (8 per cent increase in CO_2 emissions; 49 per cent reduction in emissions of other greenhouse gases; yielding a total reduction of nine per cent). Unit is in million tonnes of CO_2 equivalents per year. Data sources, see endnote 86.

4.4 Emission pathways consistent with the 1.5°C and 2°C targets

Figure *27* shows the future emissions for Norway under the assumption that the remaining emissions compatible with the 1.5°C and 2°C targets (from Table *2*) are evenly distributed between all nations, regardless of historical emissions and current economic, technological and societal development.

With a 50 per cent likelihood that the global temperature will not exceed 1.5°C (Figure *27*, left), Norway's emissions must be reduced by 21 per cent per year. This corresponds to five years of current greenhouse gas emissions (Table *2*). Reductions in line with the 2°C target is 4.1 per cent per year, corresponding to 30 years of current greenhouse gas emissions in Norway.

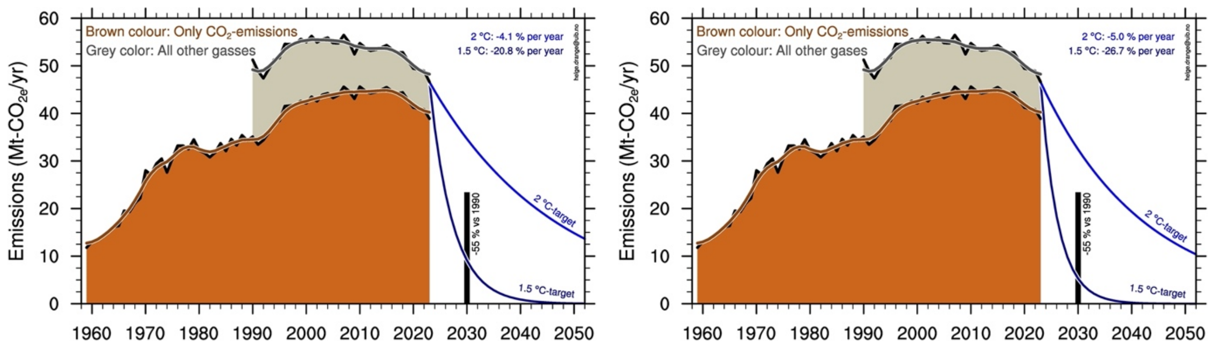

Figure 27. As Figure 26, but including Norway's 2030 climate target (55 per cent reduction in the total greenhouse gas emissions compared to 1990, see endnote 87), and emission curves in line with a 50 per cent likelihood of reaching the 1.5°C and 2°C targets (left) and similarly with 67 per cent likelihood (right), calculated based on Table 2. Annual reductions in percentage are shown at the top right of the figures. Unit is million tonnes of CO_2 equivalents per year.

For a two-thirds (67 per cent) likelihood for limiting global warming to 1.5°C, Norway's emissions must be reduced by 27 per cent per year, or that current emissions can continue for four years, with zero-emissions thereafter. For the 2°C target, annual emissions must decrease by five per cent per year, corresponding to 24 years of current greenhouse gas emissions in Norway.

To put these emission reductions into context, Norway's greenhouse gas emissions decreased by 3.2 per cent between 2019 and 2020 (endnote 86), i.e., during the peak of the COVID-19 pandemic. Globally, total greenhouse gas emissions decreased by 5.5 per cent during the pandemic in 2020 (endnote 79). Based on national and global emission reductions in the exceptional year 2020, Figure *27* illustrates the magnitude of emission reductions needed to limit global warming to 1.5°C and 2°C.

4.5 Emissions from Barents Sea South and Barents Sea South-East compared with the 1.5°C and 2°C targets

The magnitude of the emissions embedded in BSS and BSSE can be quantified relative to Norway's domestic 2023-emissions as shown in Table *3*. Alternatively, the emissions can also be quantified relative to the allowable emissions that are in line with the 1.5°C and 2°C temperature targets.

The latter can be estimated by assuming that the remaining global greenhouse gas emissions consistent with the 1.5°C and 2°C temperature targets are equally distributed between all nations, named "residual emissions" in the following.

It should here be noted that the assumption that forthcoming emissions are evenly distributed among all nations is a minimum approach and does not involve any form of fare share considerations based on historical emissions, technological or sustainable development, gross domestic product, etc. (endnote 88).

From Table *2*, it follows that the 1.5°C target with a 50 per cent likelihood corresponds to 5.4 years of Norway's 2023 emissions. Since Norway's 2023 emissions are 46.6 Mt-CO_{2e}

(endnote 83), 5.4 years adds up to 252 $Mt-CO_{2e}$. Compared to e.g. the BSS-Median emission estimate of 5148 $Mt-CO_{2e}$ (Table *3*), this implies that BSS-Median overshoot Norway's "residual emissions" by a factor 22 (the ratio of 5148 $Mt-CO_{2e}$ and 252 $Mt-CO_{2e}$).

Similar considerations can be applied to the other emission scenarios, combined with the 1.5°C and 2°C targets with 50, 67 and 83 per cent likelihood to be met. The resulting "residual emission" factors are given in Table *4*, with the factors rounded to one decimal for the smallest values and the nearest integer for the larger values, for convenience.

Emission scenario	**Emissions in $Mt-CO_{2e}$**	**1.5°C target**			**2°C target**		
		50%	**67%**	**83%**	**50%**	**67%**	**83%**
BSSE2020-Low	106.9	0.4	0.6	0.9	0.1	0.1	0.1
BSSE2020-High	388	1.5	2.1	3.1	0.3	0.3	0.4
BSS-Median	5184	21	28	41	3.8	4.6	5.5
BSS-Max	6336	25	34	51	4.6	5.6	6.7
BSSE-Median	722	3	4	6	0.5	0.6	0.8
BSSE-Max	1627	6	9	13	1.2	1.4	1.7
Sum-Median	5906	24	31	47	4.3	5.2	6.3
Sum-Max	7963	32	42	63	5.8	7.1	8.5

Table 4. First and second columns are identical to Table 3, and give an overview of the considered greenhouse gas emission scenarios and the corresponding emissions.

The three "1.5°C target" columns show, with 50, 67 and 83 per cent likelihood that global warming will not overshoot 1.5°C, the "residual emission" factor for the different BSS and BSSE emission scenarios (see text for a description of the method). In the table, "Sum-Median" is the sum of "BSS-Median" and "BSSE-Median", whereas "Sum-Max" is the sum of "BSS-Max" and "BSSE-Max". Since the "residual emission" factors are rounded values, the numerical value of "Sum-Median" may differ from the sum of "BSS-Median" and "BSSE-Median" by a value of ±1.

The three "2°C target" columns are similar to the 1.5°C target columns, but with 2°C warming as the target.

In the following, the "residual emission" factors of the sum of BSS and BSSE are presented for the median and maximum scenarios ("Sum-Median" and "Sum-Max" in Table *4*), as well as for the early production scenario for the Barents Sea South-East region, BSSE2020-High.

The 1.5°C target with a 50 per cent probability:

This target corresponds to 5.4 years of Norway's domestic 2023 emissions (Table 2). Since the sum of BSS and BSSE for the median and maximum emissions are respectively 127 and 172 times larger than Norway's domestic 2023-emissions; the sum of BSS and BSSE overshoot Norway's "residual emissions" by a factor 24 (median emissions) and 32 (maximum emissions).

Similarly, the emission for the early production scenario BSSE2020-High, exceeds Norway's "residual emissions" by a factor 1.5.

For BSS-Median and BSS-Max, these emissions overshoot Norway's "residual emissions" by a factor 21 and 25, respectively.

For BSSE-Median and BSSE-Max, Norway's "residual emissions" are overshoot by a factor 3 and 6, respectively.

The 1.5°C target with a 67 per cent probability:

This target corresponds to 4.1 years of Norway's domestic 2023 emissions (Table 2). Consequently, the sum of BSS and BSSE overshoot Norway's "residual emissions" by a factor 31 (median emissions) and 42 (maximum emissions).

For BSS-Median and BSS-Max, these emissions overshoot Norway's "residual emissions" by a factor 28 and 34, respectively.

For BSSE-Median and BSSE-Max, Norway's "residual emissions" are overshoot by a factor 4 and 9, respectively.

The 2°C target with a 50 per cent probability:

This target corresponds to 29.7 years of Norway's domestic 2023 emissions (Table 2). This means that the sum of BSS and BSSE overshoot Norway's "residual emissions" by a factor 4.3 (median emissions) and 5.8 (maximum emissions).

Similarly, the emission for the early production scenario BSSE2020-High, corresponds to about one third of Norway's "residual emissions".

For BSS-Median and BSS-Max, these emissions overshoot Norway's "residual emissions" by a factor 3.8 and 4.6, respectively.

For BSSE-Median and BSSE-Max, Norway's "residual emissions" are overshoot by a factor 0.5 and 1.2, respectively.

The 2°C target with a 67 per cent probability:

This target corresponds to 24.3 years of Norway's domestic 2023 emissions (Table 2). This means that the sum of BSS and BSSE overshoot Norway's "residual emissions" by a factor 5.2 (medium emissions) and 7.1 (maximum emissions).

The emission for the early production scenario BSSE2020-High, corresponds to about one third of Norway's "residual emissions".

And finally, for BSS-Median and BSS-Max, these emissions overshoot Norway's "residual emissions" by a factor 4.6 and 5.6, respectively.

For BSSE-Median and BSSE-Max, Norway's "residual emissions" are overshoot by a factor 0.6 and 1.4, respectively.

4.5.1 Summary

With the assumption that future greenhouse gas emissions are evenly distributed among all nations, the median emissions from the sum of BSS and BSSE exceeds Norway's "residual emissions" within the 1.5°C target by more than a factor 24. For BSS alone, the factor is 21 or larger; whereas for BSSE the factor is 3 or larger.

For maximum emissions from BSS and BSSE, the factor is 32 or higher. For BSS alone, the factor is 25 or larger; whereas for BSSE the factor is 6 or larger.

In this perspective, the emissions from BSS and BSSE, both individually and combined, are incompatible with the 1.5ºC target (Table *4*).

For the 2ºC target, BSS-Median is at least a factor 3.8 (with 50 percent likelihood) higher than Norway's "residual emissions". For BSSE, the emissions add up to at least half of Norway's "residual emissions".

5. What are some climate consequences of these embedded emissions in the Barents Sea South and Barents Sea South-East for linear and non-linear changes in climate in Norway?

5.1 Linear relationship

A particularly central and well-established result from climate research, at least since the fifth main report from the UN Climate Panel 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-emission to a (probable) future global temperature. Figure *28* illustrates the close to linear relationship between cumulative CO_2 emissions and global warming.

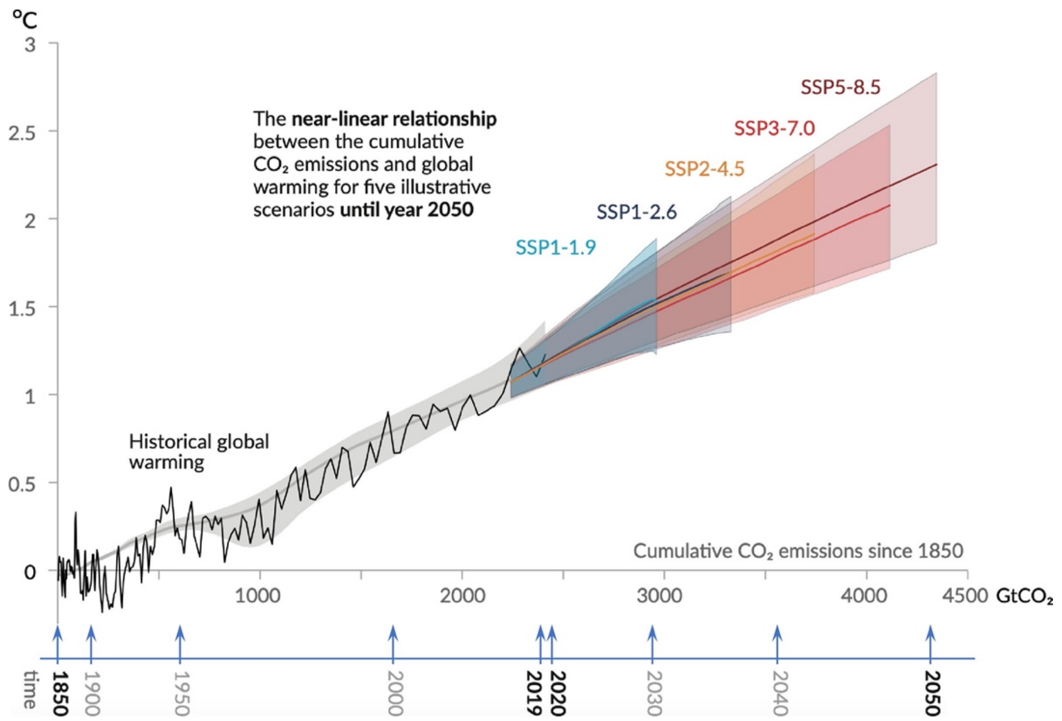

Figure 28. Correlation between the sum of global CO_2 emissions since 1850 (in billion tonnes of CO_2; top horizontal axis) versus the change in global temperature since 1850-1900 (°C; vertical axis). In addition, the timing of the cumulative CO_2-emissions is shown on the bottom horizontal axis. Black curve shows historical correlation between CO_2 emissions and change in global temperature for the period 1850-2019; the colour shading shows the corresponding relationship for different emission scenarios. Figure from endnote 89.

The relationship described above and illustrated in Figure *28* 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 90), 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 5 shows the temperature effect of the Barents Sea scenarios when the connection between emissions and temperature, as mentioned above, is taken into account. Based on this, the sum of BSS and BSSE are 0.003°C (for median emissions) and 0.004°C (for maximum emissions).

Emission scenario	Emissions in Mt-CO_{2e}	Resulting global warming (°C)
BSSE2020-Low	106.9	0.0001
BSSE2020-High	388	0.0002
BSS-Median	5184	0.0026
BSS-Max	6336	0.0032
BSSE-Median	722	0.0004
BSSE-Max	1627	0.0008
Sum-Median	5906	0.003
SUM-Max	7963	0.004

Table 5. First and second column: Overview of the greenhouse gas emission scenarios and emissions discussed (identical to Table *3*). The rightmost column gives the estimated global temperature contributions for the different scenarios based on the relationship that 100 billion tonnes of CO_2 corresponds to a global temperature rise of 0.05°C (endnote 90).

It is hard to comprehend what 0.003 or 0.004°C of warming means or implies. 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 1.3°C (Figure *1*). Compared to this, the BSS and BSSE resource estimates are clearly non-negligible.

The contributions from BSS and BSSE emissions 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. Since 1960, the Earth's climate system has increased its heat content by roughly 400 x 10^{21} Joules, see Figure 5. This warming can be attributed to the historical greenhouse gas emissions, which for the period 1960-2023 are 1512 billion tonnes of CO_2 (endnote 91).

Based on this, we can estimate the contribution of BSS and BSSE to increasing the Earth's total heat content. Since 1512 billion tons of CO_2 have contributed to a warming of the Earth system of 400 x 10^{21} Joules (from the previous paragraph), this means that the combined BSS and BSSE resource estimates are equivalent to a warming of the Earth system of 1.6 x 10^{21} Joules (median emissions) and 2.1 x 10^{21} Joules (maximum emissions).

For BSS, the equivalent warming of the Earth system is 1.4 x 10^{21} Joules (median emissions) and 1.7 x 10^{21} Joules (maximum emissions).

For BSSE, the equivalent warming of the Earth system is 1.9 x 10^{20} Joules (median emissions) and 4.3 x 10^{20} Joules (maximum emissions).

To put the above warming estimates in perspective, we can compare these with the total energy production in Norway for the period 2020-2022 of around 150 TWh (endnote 92). Since 1 J = 2.78 x 10^{-16} TWh, this means that the sum of the BSS and BSSE resource estimates produce a heating contribution corresponding to 2,900 and 3,900 times Norway's total annual energy production for the median and maximum resource estimates, respectively.

For BSS, the heating factor is 2,500 (for median emissions) and 3,100 (for maximum emissions) times Norway's total annual energy production.

For BSSE, the above figures are 350 (for median emissions) and 800 (for maximum emissions), respectively.

The main part of the heating effect of the emissions from BSS and BSSE will be found in the ocean as increased sea surface and sub-surface temperature (Figure 5), and will consequently contribute to increased sea level, as well as impacting marine ecosystems for a very long time (many hundred to several thousand years forward in time).

(ii) Any CO_2 emission, regardless of size and where the emission occurs geographically, will have 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 53), or approximately 30 human generations forward in time. Consequently, emissions from BSS and BSSE will affect humanity over a very long time horizon. It is difficult to specify the consequences for society 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 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 the pH-value throughout the World's oceans, with the fastest "acidification" in cold waters (endnote 93). It is difficult to specify the impact of the emissions from BSS and BSSE, 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 the air temperature increases, the air's ability to retain moisture increases by around seven per cent (endnote 94). This factor is a key explanation to why the average amount of precipitation in Norway has increased by around 20 per cent in the last 100 years (endnote 95), with an even greater increase for large amounts of precipitation/extreme precipitation (endnote 96). The emissions from BSS and BSSE will contribute to continued increase in average rainfall, as well as more extreme rainfall events in Norway.

(v) Greenhouse gas emissions affect the Earth's energy budget (Figure 5), 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 *9*). 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 meters (endnote 97).

Based on this, the sum of BSS and BSSE will lead to the September extent of Arctic sea ice to be reduced by around 18,000 and 24,000 square kilometres for the median and maximum resource estimates, respectively. By comparison, Oslo's area is 450 square kilometres, so the median and maximum resource estimates correspond to 40 and 53 times the area of Oslo.

For BSS, the median and maximum resource estimates correspond to 15,500 and 19,000 square kilometres reduced sea ice extent for median and maximum emissions, respectively; corresponding to 35 and 42 times the area of Oslo.

For BSSE, the median and maximum resource estimates correspond to 2,200 and 4,900 square kilometres, or 5 and 11 times the area of Oslo.

(vi) Similar to sea ice, there is also a close one-to-one relationship between increased global temperature and reduced extent of northern hemisphere snow in spring. This applies to both observed (endnote 98) and modelled (endnote 99) snow extent.

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

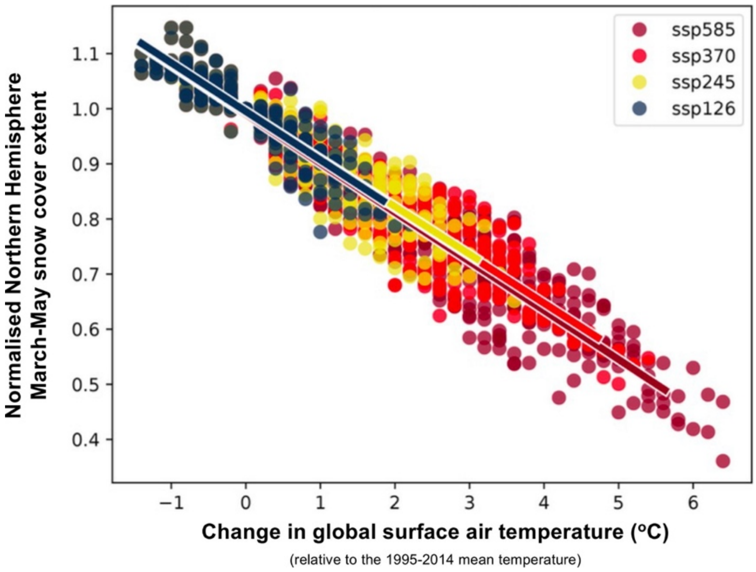

Figure 29. Correlation between change in global temperature (°C; relative to the temperature for the period 1995-2014; (horizontal axis) and normalized northern hemisphere snow cover for the months March, April and May (vertical axis; here value 1.0 corresponds to the average distribution of snow for the period 1995-2014). Based on figure 9 in endnote 99.

The relationship is that the 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. This leads to the relationship (endnote 100)

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

Consequently, the sum of BSS and BSSE will cause the northern hemisphere extent of snow in March to May to be reduced by around 7,000 and 9,600 square kilometres for the median and maximum resource estimates, respectively. By comparison, Oslo's area is 450 square kilometres, corresponding to 16 and 21 times the area of Oslo.

For BSS, the median and maximum resource estimates correspond to 6,200 and 7,600 square kilometres reduced northern hemisphere snow extent in March to May for median and maximum emissions, respectively; corresponding to 14 and 17 times the area of Oslo.

For BSSE, the median and maximum resource estimates correspond to 900 and 2,000 square kilometres, or 2 and 4 times the area of Oslo.

(vii) When we move upward in the terrain, we experience that the air temperature drops. The reason for this is that the air pressure, i.e., the weight of air above us, decreases. Typically, the temperature drops by 0.7ºC per 100 meters of elevation. This relationship has a direct influence on the snow line, the elevation where snow remains on the ground. For each degree of temperature increase, the snow line will rise by approximately 140 m.

For Norway and for those regions with a typical winter temperature around 0ºC, warming is experienced as finding the snow line higher in the terrain. For the coastal city Bergen, as an example, the winter (November to March) temperature has increased by 1.3ºC in the last 50 years (endnote 101), which means that the snow line is found approximately 180 m higher today than 50 years ago. For Norway, the emissions BSS and BSSE will contribute to increased temperature, moving the snow line to higher elevations and further shorten the winter season.

5.2 Non-linear relationships

As described above and illustrated in Figure 10, seven tipping elements can be activated for a global warming between 1.5ºC and 2ºC. Five of these tipping elements will affect Norway's climate (and society and ecosystems) directly. This applies to 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 emissions of methane); 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 exact the temperature thresholds for when the tipping elements turn unstable. 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 102). This is of concern since West Antarctica alone can contribute with several (3-5) meters of global sea level rise.

For the Norwegian coast, assuming continued large emissions and partial collapse of the ice in West Antarctica, the sea level may rise by 1-2 m towards the year 2100 (endnote 46).

As a remark to the above: The fast 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" cannot be ruled out.

For the BSS and BSSE resource estimates, it cannot be ruled out that these may activate one or more of the tipping elements that may occur with a global temperature increase of between 1.5^{o}C and 2^{o}C, including the collapse of the West Antarctic ice sheet.

Bergen, 12 August 2024

Helge Drange

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30 million km^2 = 3 x 107 km^2.

Since the snow cover is reduced by around 8 percent (relative to the 1995-2014 spread of snow) for every degree global temperature increases, the linear relationship can be expressed as

warming of 1°C corresponds to $0.08 \times (3 \times 10^7\ km^2) = 2.4 \times 10^6\ km^2$

with reduced snow cover.

Furthermore, we have 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) that

100 billion tonnes of CO_2 corresponds to a warming of 0.05°C,

or

2x1012 tonnes of CO_2 corresponds to a warming of 1°C.

Combined, the two connections give that a

greenhouse gas emissions of $2x10^{12}$ tonnes of CO_2 result in 2.4 x 10^6 km^2 reduced snow cover,

or simplified that

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

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