Expert report at the request of the law firm Simonsen Vogt Wiig in case 24-036810ASD-BORG/02

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I have been asked to address the following questions:

1. Please describe your background and scientific expertise.
2. Is there an established method to quantify climate change impacts from project-level greenhouse gas emissions from oil and gas extraction?
3. Using robust scientific methods, could you quantify some climate change impacts of the project-level emissions from Breidablikk (107 $MtCO_2$), Tyrving (12 $MtCO_2$), and Yggdrasil (365 $MtCO_2$) including on sea levels, glacier mass, and economic losses?
4. Can you assess these emissions against the remaining global carbon budget for limiting warming to 1.5°C with 50%, 67% and 83% likelihood, accounting for the emissions of other global fossil fuel projects?
5. To what extent are the projected emissions from Breidablikk, Tyrving and Yggdrasil consistent with a per capita allocation of the remaining carbon budget for Norway in 2021 (Breidablikk) and 2024 (all fields)?

1. Please describe your background and scientific expertise.

I am a Senior Research Fellow in Climate Science and the Law at the University of Oxford's School of Geography and the Environment and the Deputy Director of the Oxford Sustainable Law Programme, a joint institute of the University's School of Geography and Faculty of Law. I have a DPhil in climate science and glaciology from the University of Oxford and have conducted research in the areas of climate change impacts on health, glaciers, and extreme weather events, and on climate change mitigation. My research has been published in leading scientific journals including Science, Nature Geoscience and Nature Climate Change and cited over 1,100 times.

I have particular expertise in understanding and quantifying the impacts of climate change, and co-led a recent Wellcome Trust project that brought together leading climate scientists and health researchers from around the world to draft guidelines for quantifying the attributable impacts of climate change on human health, the outcome of which will be published in summer 2025.

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2. Is there an established method to quantify climate change impacts from project-level greenhouse gas emissions from oil and gas extraction?

There are multiple established methods to quantify climate change impacts from project-level greenhouse gas emissions. These have been published in peer-reviewed literature and included in the Intergovernmental Panel on Climate Change (IPCC) reports and show that greenhouse gas emissions from individual emitters contribute to the impacts of climate change. I summarise these approaches and divide them into two complementary lines of evidence. First, I explain that the approximately linear relationship between cumulative carbon dioxide (CO_2) emissions and global warming, coupled with the clear scientific understanding of the relationship between global warming and local changes in the climate, provides strong scientific evidence on the link between emissions contributions of any size and global climate change impacts. This scientific assessment reflects that of the IPCC, which noted that “Many changes in the climate system become larger in direct relation to increasing global warming. They include increases in the frequency and intensity of hot extremes, marine heatwaves, heavy precipitation, and, in some regions, agricultural and ecological droughts; an increase in the proportion of intense tropical cyclones; and reductions in Arctic sea ice, snow cover and permafrost.”[1]

Second, I provide a summary of the scientific literature (and methods used therein) that quantifies location-specific climate change impacts that are attributable to individual emissions sources. Together these form a demonstration of the processes by which small emissions contributions cause climate change impacts and a quantification of some of these impacts.

a. All CO_2 emissions cause climate change impacts

In this section, I explain how all emissions of CO_2 contribute to rising global temperatures which, in turn, leads to a range of climate change impacts occurring worldwide.

i. Every tonne of CO_2 emitted causes global warming

Scientific evidence shows that every tonne of CO_2 emitted into the atmosphere contributes to global warming. That is, the total cumulative amount of CO_2 released over time is what primarily determines long-term global temperature rise.

This principle was first shown by a series of articles in 2009.[2–6] Importantly, these studies showed that the global mean surface temperature increases approximately **linearly** with the total amount of CO_2 emitted over time. This insight underpins the IPCC’s finding that any limit on temperature rise corresponds to a finite carbon budget and that stopping the increase in global warming requires reducing net CO_2 emissions to zero.

This near-linear relationship between cumulative CO_2 emissions and global temperature rise is now well established. It is reflected in the concept of the Transient Climate Response to cumulative CO_2 emissions (TCRE),[7] which measures how much the global average temperature increases per 1,000 gigatonnes (Gt) of CO_2 emitted. According to the IPCC’s Sixth Assessment Report (henceforth, AR6), the TCRE is 0.27–0.63°C per 1,000 $GtCO_2$ with a best estimate of about 0.45°C.[8]

Because every tonne of CO_2 emitted permanently adds to global warming (see figure 1, taken from IPCC AR6), there is no threshold below which emissions are harmless: all emissions, including contributions from individual actors or projects, result in rising global temperatures.

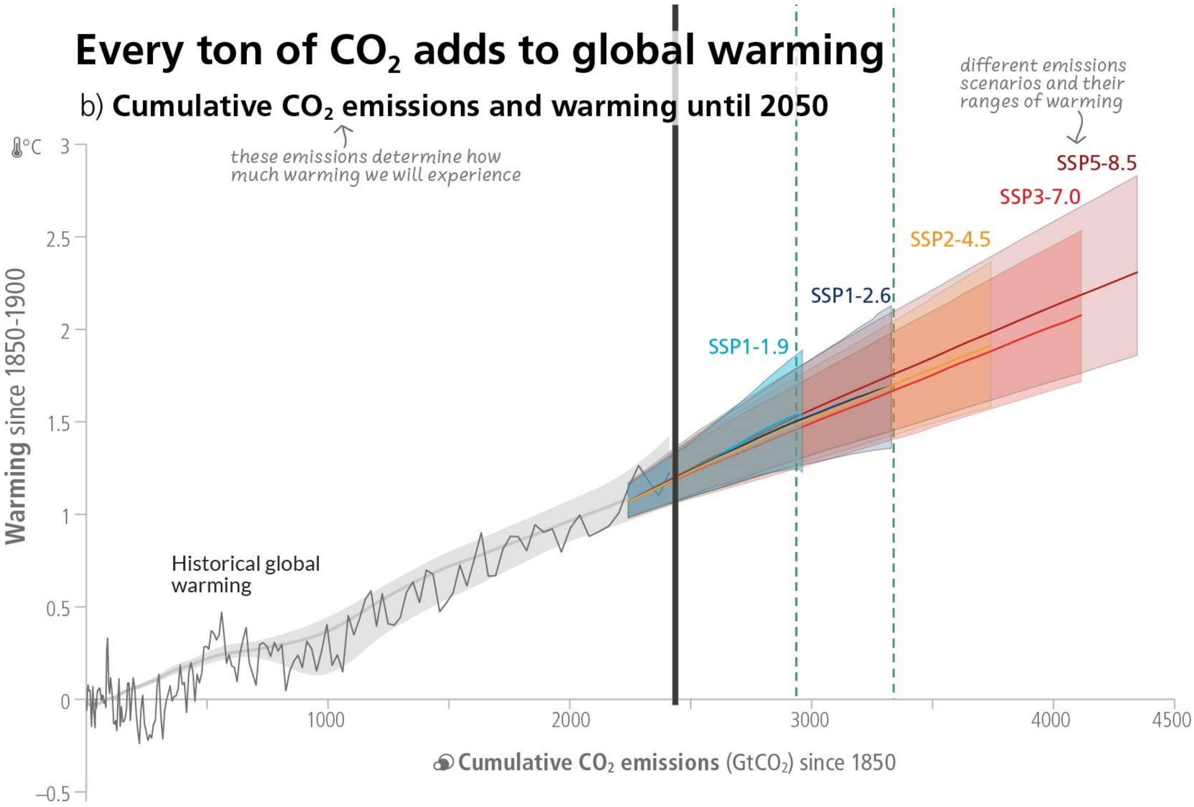

Figure 1: Figure taken from the IPCC AR6 Synthesis Report. "This figure displays the relationship between cumulative CO_2 emissions and the increase in global surface temperature. Historical data (thin black line) shows historical CO_2 emissions versus observed global surface temperature increase relative to the period 1850–1900. The grey range with its central line shows a corresponding estimate of the human-caused share of historical warming. Coloured areas show the assessed very likely range of global surface temperature projections, and thick coloured central lines show the median estimate as a function of cumulative CO_2 emissions for the selected scenarios SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5. Projections until 2050 use the cumulative CO_2 emissions of each respective scenario, and the projected global warming includes the contribution from all anthropogenic forcers"[9]

ii. From emissions to impacts

Greenhouse gas emissions drive global warming through well-understood physical processes. That warming, in turn, leads to a cascade of impacts on the climate system. There is a direct chain of causation from emissions to temperature rise, and from temperature rise to specific physical and socioeconomic impacts.[1] These facts constitute the basis of how human influence on the climate can be causally linked to climate change impacts occurring worldwide.

The IPCC AR6 concluded that it is unequivocal that human influence, primarily through greenhouse gas emissions, has warmed the atmosphere, ocean, and land. In the 2010s, human activity had raised global surface temperatures by about 1.07 °C compared to preindustrial levels.[1] As of 2024, human-caused global warming reached 1.36 °C.[10] This warming drives a cascade of changes across the climate system.

As the climate warms, daily temperatures are changing in both how warm typical days are and how often extremely hot days occur. This is not just an increase in average temperatures, instead, the entire distribution of temperatures shifts. The distribution refers to how temperatures are spread out over time, including the common, mild days as well as the rare, extreme hot days. When the distribution shifts toward higher temperatures, as is occurring nearly worldwide, very hot days become more common and hotter than they would have been in the absence of human-induced climate change. According to Chapter 11 of the IPCC AR6 Working Group 1, it is virtually certain that extreme heat events have increased in frequency and severity across most land regions.[11] These changes raise the risk of dangerous heatwaves and pose serious challenges to public health and environmental safety.

The precise amount of warming varies around the globe, due to differences in how energy and moisture are distributed throughout the climate system. For instance, land surfaces warm faster than oceans due to their lower heat capacity (in other words, the same amount of energy input to the land would raise its temperature more than for the sea). Polar regions, particularly the Arctic, are warming much faster than the global average, in part due to ice–albedo feedbacks, where melting ice exposes darker surfaces that absorb more solar energy. Meanwhile, changes in atmospheric circulation patterns can shift storm tracks or intensify drought in some subtropical regions. These regional variations are driven by complex interactions among the components of the climate system, such as ocean currents, thermal winds, soil moisture, or vegetation cover.

As the atmosphere warms, it can hold more moisture, a relationship governed by a well-established physical principle known as the Clausius–Clapeyron relation. For each degree Centigrade of warming, the atmosphere's capacity to retain water vapor increases by about 7%. This added moisture contributes to heavier rainfall when conditions trigger precipitation. According to Chapter 11 of the IPCC AR6, it is likely that heavy rainfall events have also become more common globally. The report identifies human-induced greenhouse gas emissions as the principal driver behind these observed trends. Due to this well-established relationship between temperature and atmospheric moisture, every incremental increase in temperature is associated with increasing extreme rainfall.

Not all climate responses are gradual. Chapter 8 of the IPCC AR6 Working Group I (Water Cycle Changes) highlights the possibility of abrupt changes, defined as "a regional-to-global scale change in the climate system that occurs faster than the typical rate of changes in its history, implying non-linearity in the climate response".[12] Such abrupt changes often result from positive feedbacks within the climate system, where self-reinforcing processes lead to instability and cause the system to cross a tipping point, a threshold beyond which a rapid shift to a different state occurs. An example is the risk of a severe weakening or collapse of the Atlantic Meridional Overturning Circulation which could occur by 2100, which would "[cause] abrupt and profound changes in the global hydrological cycle". The exact rise in temperature that might trigger such tipping points is not known precisely, although several tipping points that include the collapse of the Greenland Ice Sheet, the die-off of tropical coral reefs and the collapse of the Atlantic Meridional Overturning Circulation could occur at temperature rises of between 1.5-2 °C.[13] Consequently, with global temperatures already approaching 1.5 °C above pre-industrial levels, every small rise in temperature increases the risk of tipping points being crossed.

As climate extremes intensify, their effects on society and ecosystems are becoming more severe and, in some cases, irreversible. The IPCC AR6 Working Group II (Impacts, Adaptation and Vulnerability) concludes that "the rise in weather and climate extremes has led to some irreversible impacts as natural and human systems are pushed beyond their ability to adapt."[14] For example, the increased frequency and severity of extreme heat, drought, and heavy precipitation are already reducing agricultural productivity, straining water resources, and increasing the risk of climate-related mortality. Some of these impacts also exhibit a nonlinear response, meaning that risks can increase disproportionately with further warming, accelerate, or trigger irreversible changes. Examples include global aggregate economic damages, declining crop yields, and threats to the habitability of small islands.

b. Peer-reviewed source attribution studies have established methods to link emissions from individual emitters to specific climate damages

Because global temperature rise scales linearly with cumulative emissions, and because temperature rise drives physical and socioeconomic impacts, consequences of greenhouse gas emissions from any source, including individual fossil fuel projects, can now be quantified. This forms the basis for **source attribution**: an area of climate research that links emissions from particular sources (such as companies, countries, or sectors) to specific climate outcomes, such as sea level rise, temperature extremes, economic costs, or excess mortality. In this section, I summarise methods used in peer-reviewed studies that quantify the contribution of individual actors to climate change and its impacts and provide examples of climate change impacts that have been assessed using these approaches. While many of these studies quantify impacts attributable to individual countries or companies' emissions, there is no scientific reason why the same methods applied to project-level emissions would not also lead to a finding that those emissions had made a discernible contribution to the assessed climate change impacts.

Three methods are described. The first uses the linearity of TCRE to estimate the contribution of CO_2 emissions (for instance, from individual projects) to global warming. Studies applying this method are detailed in part 2bi. The other two methods, used by studies presented in part 2bii and 2biii, include modelling counterfactual scenarios to assess how the probability or intensity of individual weather events would have changed but for an individual entity's greenhouse gas emissions, relative to the observed climate. These studies typically assume a linear link between warming and specific impacts. Here I explain the three main methods used in greater detail.

i. Linear relationship between cumulative CO_2 emissions and global temperature change

These studies rely on the linear relationship between global temperature change and cumulative CO_2 emissions. Thus, the simplest method to estimate the contribution of project-level CO_2 emissions to climate change involves:

- Estimating the cumulative CO_2 emissions from the project
- Multiplying those emissions by the TCRE using the IPCC's best estimates and uncertainty ranges, to quantify the project's contribution to GMST increase.
- Linking the resulting GMST increase to physical and socioeconomic climate impacts, based on established impact attribution studies.

Some studies that relied on the TCRE for their analysis are:

Klöwer et al. 2021 quantified the contribution of the aviation sector to climate change, finding that "Aviation contributed approximately 4% to observed human-induced global warming to date, despite being responsible for only 2.4% of global annual emissions of CO_2".[15]

Jones et al. 2023 provide an annually updated dataset that quantifies the contribution of individual countries to global warming, based on their historical emissions of CO_2, methane (CH_4), and nitrous oxide (N_2O).[16]

ii. 'But for' approach

One common approach involves using emissions-driven climate models that simulate both the historical climate and a counterfactual climate, in which specific human-caused greenhouse gas and aerosol emissions are excluded. These climate models estimate how the climate would have evolved if specific emissions had not taken place and can be used to assess the resulting impacts. This approach aligns with the legal concept of 'but for' causation in that it quantifies, but for the emissions from a given source, how the resulting climate response would have been differed. Examples that apply such approaches include:

Ekwurzel et al. 2017, building on the work of Heede 2014,[17] quantified how much of the observed rise in atmospheric CO_2, global mean surface temperature, and global sea level can be attributed to the emissions of major fossil fuel producers. Their study concludes as follows: "Our study demonstrates that **the proportional increase in atmospheric carbon dioxide, GMST, and GSL**—key indicators of human impact on the global environment—**from emissions traced to major carbon producers is quantifiable and substantial**. The analyses presented here could be extended to examine the contribution of emissions traced to major carbon producers to other impacts".[18]

Licker et al. 2019 attributed 51% of the recent acidification of the oceans to the emissions from 1965 to 2015 of the 88 largest industrial carbon producers.[19]

Beusch et al 2022 found that greenhouse gas emissions from 1991 to 2030 by five major emitters (China, US, EU-27, India, and Russia) will double the number of countries experiencing extreme hot years every second year. Their analysis demonstrates how **emissions from a small group of high-emitting countries can significantly amplify global exposure to extreme heat**.[20]

Dahl et al. 2023 attributed a rise in vapor pressure deficit, a measure of the atmosphere's drying power, and an increase in burned area in the western United States and southwestern Canada to the emissions from 88 major fossil fuel producers since 1986, contributing to an increase in fire activity and prolonged megadrought conditions.[21]

Quilcaille et al. 2024 attributed the increased likelihood of observed extreme heatwaves to the historical emissions of 122 fossil fuel and cement producers. Their analysis showed that even the emissions from individual companies can significantly influence the probability of extreme heat events. The authors state that "**Even small carbon majors enable heatwaves with their sole contribution**."[22]

Callahan and Mankin 2025 found that emissions from major fossil fuel companies caused 28 trillion dollars in heat-related economic losses from 1991-2020. They state that "Drawing **quantitative linkages between individual emitters and particularized harms is now feasible**, making **science no longer an obstacle to the justiciability of climate liability claims**."[23]

Schöngart et al. 2025 showed how greenhouse gas emissions from 1990–2020 from the consumption and investments of the wealthiest population have disproportionally influenced present day climate change. Their analysis connects these emissions not only to global warming in general, but also to specific impacts such as increased heat extremes and intensified droughts in the Amazon region.[24]

iii. Linearity between contribution to warming and impact

Some studies assume that an actor's share of GMST scales linearly with their contribution to specific climate and weather extremes. This approach simplifies attribution by proportionally distributing impacts based on contributions to warming, rather than modelling counterfactual 'but for' emissions scenarios. Examples of studies that apply this approach include:

Otto et al. 2017 used climate models to simulate historical and counterfactual scenarios of the 2013/14 Argentinian heatwave and assumed a linear link between each region's contribution to GMST and its share of the change in event probability. Otto et al. 2017 showed that it is now scientifically possible to quantify the contribution of individual countries and regions to the impact of climate change on specific extreme weather events. Using the 2013 Argentinian heatwave as a case study, they found that greenhouse gas emissions from the EU28 increased the likelihood of the event by between 19%-60%.[25]

Lott et al. 2021 extended this logic, estimated the share of the probability of an extreme heatwave that was attributable to climate change, and distributed that cost among individuals based on their cumulative emissions as a proportion of total global emissions.26 attributed a fraction of the probability of an extreme event to the carbon emissions of an individual. They illustrate the methodology with an example of the 2018 summer heatwave in eastern China and its impact on aquaculture and found that an individual is responsible for between 0.53 and 18.10 yuan, depending on their age and their country's emissions. These findings were based on individuals producing, on average, between 10-192 tonnes of CO_2 emissions.[26]

3. **Using robust scientific methods, could you quantify some climate change impacts of the project-level emissions from Breidablikk (107 $MtCO_2$), Tyrving (12 $MtCO_2$), and Yggdrasil (365 $MtCO_2$) including on sea levels, glacier mass, and economic losses?**

a. Quantifying sea level rise contributions of project emissions

To estimate the sea level rise contributions resulting from the emissions of each of the three projects, I apply methods described in the previous section. As a simple example, I assume that the contribution of projects to GMST scales linearly with their contribution to sea level rise. Because this assumption is valid for events largely influenced by thermodynamics (as discussed in part 2aii) I give the example of global mean sea level rise (GMSL) and apply a two-step attribution method:

- Estimate each project's contribution to GMST, by applying the TCRE. The IPCC AR6 gives a best estimate of TCRE = 0.45°C per 1000 $GtCO_2$ (likely range: 0.27–0.63°C).[8] To simplify, and because the purpose here is to show the approximate contribution of the three projects and methods that could be used to formally quantify their impacts, I use the central estimate.
- Convert this temperature increase into sea level rise. Chapter 9 of the Working Group I report (Ocean, Cryosphere and Sea Level Change) provides committed GMSL rise projections over 2000 years.[27] Since sea levels increase with global mean temperatures, the contribution that an individual project makes to sea level rise, based on its proportional contribution to climate change, depends on the total amount of global warming. These estimates imply the following ranges of sea level rise per degree of warming:

    - As a result of 2°C of peak warming: 2–6 m, corresponding to 1.0–3.0 m/°C
    - As a result of 3°C of peak warming: 4–10 m, or 1.33–3.33 m/°C
    - As a result of 4°C of peak warming: 12–16 m, or 3.0–4.0 m/°C

These ranges highlight the nonlinear and accelerating nature of long-term sea level commitment with increasing warming. By approximating a constant rate of sea level rise per degree of warming within each temperature range (i.e., treating the relationship as linear over that specific interval), I can estimate each project's contribution to committed GMSL rise based on its CO_2 emissions and associated warming. Table 1 shows the contribution of each project.

Project	Emissions ($MtCO_2$)	Contribution to global mean surface temperature rise (°C)	Contribution to global mean sea level rise at 2°C (cm)	Contribution to global mean sea level rise at 3°C (cm)	Contribution to global mean sea level rise at 4°C (cm)
Breidablikk	107	0.000048	0.0048-0.014	0.0063-0.016	0.014-0.019
Tyrving	12	0.0000054	0.00054-0.0016	0.00072-0.0018	0.0016-0.0027
Yggdrasil	365	0.00016	0.016-0.048	0.021-0.053	0.048-0.064

Table 1. Contribution to Global Mean Surface Temperature is estimated using a TCRE of 0.45°C per 1,000 $GtCO_2$, based on the IPCC AR6.[8] Contribution to Global Mean Sea Level rise is estimated using the values based on the IPCC AR6 Chapter 9.[27]

This is a simple approach that assumes linear scaling between emissions, temperature increase, and sea level rise. More precise evaluation of each project's contributions to specific climate impacts would require the use of more sophisticated methods, such as those detailed in the response to Question 2. For example, a "but for" causation framework could be applied by running counterfactual climate model simulations that remove the emissions from each individual project. This has been done for sea level rise in a climate change projection study[28] and would allow for a more accurate attribution of impacts by capturing nonlinear climate dynamics and feedbacks.

b. Quantifying project-level emissions contributions to global glacier mass loss

Observations show that global glacier mass loss is accelerating. Between 1993 and 2019, glaciers worldwide lost approximately 6,200 billion tonnes (estimated range of 4,600 to 7,800 billion tonnes) of ice.[27] The average annual rate of glacier mass loss has also increased over time. A recent assessment published in the journal *Nature* reported an average rate of ice loss of 273 billion tonnes per year between 2000 and 2023, with a 36% increase in the rate of loss between the first half of this period (2000–2011) and the second half (2012–2023).[29] Approximately 100% of observed global glacier mass loss has been attributed to human-induced climate change.[30]

To estimate each project's contribution to glacier mass loss, I first calculate its contribution to global warming using the TCRE value of 0.45°C per 1,000 Gt CO_2, as in section 3a. Glacier mass loss can then be estimated for several warming scenarios based on projections from Rounce et al. (2023),[31] applying a standard conversion factor that 362.5 billion tonnes of glacier mass loss corresponds to 1 mm of sea level equivalent (SLE).[27]

In a scenario in which global warming stabilises at 1.5°C by 2100, global glacier loss is projected to result in 90 ± 26 mm of sea level rise (measured as sea level rise or SLE), equal to approximately 32,625 billion tonnes of ice loss.[31] I make the assumption that the glacier mass loss committed at this level of warming is fully realised. This assumption is supported by the fact that temperatures typically stabilise by around mid-century in 1.5°C scenarios, and mountain glaciers have multi-decadal response times to changes in climate.[32] These facts indicate that most mountain glaciers will be adjusted to a 1.5°C temperature rise by 2100. Any additional glacier mass loss relative to that at 1.5°C, in a scenario with more global warming, can therefore be considered to be the result of that additional warming rather than the lagged effect of antecedent conditions.

I then assess the additional ice loss that would result from the emissions of the three projects by 2100 as follows:

- I calculated the ice loss under scenarios in which global temperatures reach 2°C and 3°C, relative to the 1.5°C scenario.
- I used these calculations to quantify the amount of additional glacier mass loss that would occur per degree Centigrade of additional warming above 1.5°C.
- The projected glacier mass loss projected to occur in the 21st Century as a result of each of the projects is then estimated by multiplying the warming attributable to each project by the ice mass loss projected per degree of future warming.

The incremental mass loss committed by 2100 if global temperatures exceed 1.5°C:

- As a result of 2°C peak warming by 2100: 99 ± 31 mm SLE (~35,887 billion tonnes of ice), or an additional ~3,262 billion tonnes compared to the 1.5°C scenario. This corresponds to approximately 6,524 billion tonnes per additional degree of warming (6,524 Gt/°C).
- As a result of 3°C peak warming by 2100: 125 ± 39 mm SLE (~45,312 Gt of ice), or an additional ~12,687 billion tonnes compared to the 1.5°C scenario. This corresponds to approximately 8,458 billion tonnes per additional degree of warming (8,458 Gt/°C).

Under the additional assumption that projected CO_2 emissions from each project contribute proportionally to global warming, and thereby to glacier loss, I estimate each project's share accordingly (Table 2):

Project	Emissions ($MtCO_2$)	Contribution to global mean surface temperature rise (°C)	Contribution to global glacier mass loss in a 2°C warming scenario (billion tonnes)	Contribution to global glacier mass loss in a 3°C warming scenario (billion tonnes)
Breidablikk	107	0.000048	+ 0.31	+ 0.41
Tyrving	12	0.0000054	+ 0.04	+ 0.05
Yggdrasil	365	0.00016	+ 1.04	+ 1.35

Table 2. Contribution of the three projects to global temperature change and glacier mass loss under scenarios with 2°C and 3°C of global warming by 2100.

To contextualize these figures, the density of glacier ice is approximately 0.917 Gt/km^3.[33] Consequently, each gigatonne of glacier ice corresponds to a volume of approximately 1.09 km^3. For scale, this is nearly 400 times the volume of the Great Pyramid of Giza, which has an estimated volume of approximately 0.0026 km^3.

c. Quantifying global economic impacts of project-level emissions

Greenhouse gas emissions cause a wide range of impacts globally, including heat-related mortality,[34] and damage to property, crops, and labour productivity in and following extreme weather events and as a result of slow-onset changes such as sea-level rise. To quantify the value of damages caused by emitting greenhouse gases, economists use a quantity known as the 'social cost of carbon dioxide': "the monetized value of the damages to society caused by an incremental metric tonne of CO_2 emissions".[35] The social cost of CO_2 is usually estimated using projections of population and gross domestic product (GDP) and the monetised value of climate change impacts occurring as a result of future greenhouse gas emissions, and then combining these damages into a present value by applying an economic discount rate to future damages. This metric is used widely in policy to quantify benefits of CO_2 emission reductions, including by the governments of the USA and UK. Implicit in this concept is that all CO_2 emissions cause global climate change impacts, the economic impact of which can be estimated.

Here, I apply the social cost of CO_2 to estimate the net present value of the aggregated economic damages that would be caused by the emissions associated with each of the three projects with which the present case is concerned. While other higher and lower estimates of the social cost of CO_2 exist, I apply one recent and authoritative estimate published in the journal *Nature*, that estimates the social cost of CO_2 at $185 per tonne of CO_2 ($44-$413, 5-95% range). All values are given in 2020 US dollars.

Project	Emissions ($MtCO_2$)	Discounted present value of global climate change impacts (2020 billion USD)
Breidablikk	107	19.8 (4.7 – 44.2)
Tyrving	12	2.2 (0.5 – 5.0)
Yggdrasil	365	67.5 (16.1 – 150.7)

Table 3. Global economic damages caused by the projected greenhouse gas emissions of the Breidablikk, Tyrving and Yggdrasil projects, based on the social cost of CO_2 estimates in Rennert et al. (2022).[35]

This assessment shows that even the smallest of the three projects is expected to cause over $2 billion in global climate change impacts, with substantially higher impacts for the Breidablikk and Yggdrasil projects.

d. Quantifying project-level emissions' contributions to individual extreme weather events

It is also possible to estimate individual climate change impacts that are attributable to project-level emissions. To do so, I use a case study of Hurricane Harvey, the second most expensive tropical cyclone to have affected the USA which caused extensive flooding in Houston, Texas, USA. A 2021 peer-reviewed article found that in the absence of climate change a reduced area would have been flooded by the storm, which in turn would have reduced the attributable losses by approximately $13 billion.[36]

Since there are currently no studies that quantify the economic losses from future extreme events attributable to emissions from the Breidablikk, Tyrving, and Yggdrasil projects (as these emissions have not yet occurred), I draw instead on an attribution study of a past event, Hurricane Harvey in 2017. This allows us to explore a counterfactual scenario: had the emissions from each of these three projects been released prior to 2017, what portion of the attributable losses from Hurricane Harvey might they have contributed?

I base this analysis on a peer-reviewed study by Wehner and Sampson 2021, which found that anthropogenic climate change substantially increased the rainfall and associated flooding from Hurricane Harvey. In the absence of human-induced warming, the flooded area would have been smaller, reducing the losses by an estimated $13 billion.

To estimate how emissions from each project might have contributed to this impact, I follow the following approach:

1. I calculate each project's share of cumulative CO_2 emissions if such emissions had been produced prior to 2017. In 2017, global cumulative CO_2 emissions was approximately 2,420 $GtCO_2$ (equal to 660 GtC).[37] These emission fractions are shown in the first column of Table 4.
2. I then estimate the amount of global warming each project would have contributed to, by calculating its fraction of the total CO_2-driven temperature increase. Specifically, I take the fraction of total cumulative CO_2 emissions that each project represents (as described above) and multiply it by 0.79. This factor represents the approximate share of historical global warming attributable to CO_2 emissions, based on changes in effective radiative forcing (ERF) from 1750 to 2019, as reported in the IPCC AR6[38] This gives each project's proportional contribution to historical CO_2-induced warming. These values are shown in the third column of Table 4.
3. Finally, I estimate the monetary impact by multiplying each project's warming contribution by the $13 billion in damages that are attributed to climate change by Wehner & Sampson (2021).[36] The values are shown in the fourth column of Table 4.

Project	Fraction of cumulative CO_2 emissions to 2017	Portion of anthropogenic warming to 2017	Attributable Losses ($)
Breidablikk	4.42×10^{-5}	3.49×10^{-5}	$453,934
Tyrving	4.96×10^{-6}	3.92×10^{-6}	$50,939
Yggdrasil	1.51×10^{-4}	1.19×10^{-4}	$1,550,770

Table 4. Estimated economic losses from Hurricane Harvey attributable to the emissions from the Breidablikk, Tyrving, and Yggdrasil projects, if those emissions had occurred prior to 2017. Based on the $13 billion in damages attributed to human induced climate change from Hurricane Harvey by Wehner & Sampson (2021).[36]

While the emissions from these three projects were not produced prior to 2017, this analysis demonstrates the large quantity of damages that can be attributed to emissions of the same magnitude as those that would be released by these projects.

4. Can you assess these emissions against the remaining global carbon budget for limiting warming to 1.5°C with 50%, 67% and 83% likelihood, accounting for the emissions of other global fossil fuel projects?

a. Introduction

The **carbon budget** is defined by the Intergovernmental Panel on Climate Change (IPCC) as 'the maximum amount of cumulative net global anthropogenic CO_2 emissions that would result in limiting global warming to a given level with a given probability, taking into account the effect of other anthropogenic climate forcers.'[39] The *remaining* carbon budget describes the carbon budget from a specified date onwards.

b. The remaining carbon budget at the time of project approval

The IPCC's AR6 was published in 2021-22 and presented estimates of the remaining carbon budget from 2020 onwards. To calculate the remaining carbon budget, the IPCC assessed: (i) the amount of human-induced warming for the most recent decade, (ii) the amount of warming that would result from a given amount of CO_2 emissions (the transient climate response to cumulative emissions of CO_2), (iii) the additional (lagged) warming caused by past CO_2 emissions that has not yet been realised, (iv) the amount of warming projected to occur by emissions of gases other than CO_2 (such as methane), (v) the effect of Earth system feedbacks that are not captured by the other factors.[40] In AR6 the remaining carbon budget was assessed from the start of 2020 onwards (see Table 5).[40]

Since the publication of AR6, updated estimates of the remaining carbon budget have been produced annually. These estimates apply the same method as that used in the IPCC's AR6, and are revised to account for changes since 2020, including in the observed global warming and greenhouse gas emissions produced in the interim period, which reduce the remaining carbon budget. This authoritative assessment is produced by a team of authors many of whom are among the lead authors of the relevant chapters of IPCC AR6, and led by Professor Piers Forster (University of Leeds), a Co-ordinating Lead Author of IPCC AR6, and the interim Chair of the UK Climate Change Committee, the public body established by the UK's 2008 Climate Change Act to advise on tackling and preparing for climate change.

I have been requested to provide the remaining carbon budget from the start of 2024. I take these numbers from the annual carbon budget update in Prof Forster's peer reviewed article 'Indicators of Global Climate Change 2023: annual update of key indicators of the state of the climate system and human influence' (Table 5).[41]

Likelihood of limiting global warming to within 1.5°C temperature limit	50%	67%	83%
Estimated remaining carbon budget from the beginning of 2020 ($GtCO_2$)	500	400	300
Estimated remaining carbon budget from the beginning of 2024 ($GtCO_2$)	200	150	100

Table 5. Remaining global carbon budgets from 2020 (from IPCC AR6[40]) and 2024 (from Forster et al. 2023[41]).

Since at least 2018, existing fossil fuel reserves have exceeded the remaining carbon budget. From the start of 2018, global developed reserves for which companies have a financial and regulatory commitment to extraction contained enough coal, oil and gas to produce 936 $GtCO_2$ if exploited and those fossil fuel products combusted.[42] These 'committed emissions' from global fossil fuel reserves far exceeded the remaining carbon budget, which stood at 580 $GtCO_2$ (420 $GtCO_2$) for a 50% (66%) probability of limiting global temperature change to 1.5°C in 2018.[43] The remaining carbon budget continues to far exceed the committed CO_2 emissions from developed oil and gas fields and coal mines. At the start of 2023, committed CO_2 emissions stood at 915 $GtCO_2$, an amount several times greater than the size of the remaining carbon budget.[44]

The development of new fossil fuel reserves would be inconsistent with remaining within the remaining carbon budget globally; indeed, a substantial portion of fossil fuel reserves that are currently being exploited could not be exploited in full if global temperatures are to be kept to below 1.5°C. The emissions that would be produced from the development of these three new fields would therefore be inconsistent with limiting emissions in line with the remaining carbon budget.

5. To what extent are the projected emissions from Breidablikk, Tyrving and Yggdrasil consistent with a per capita allocation of the remaining carbon budget for Norway in 2024?

a. Carbon emissions of each project

The projected Scope 1-3 emissions that would result from the production and combustion of the oil and gas fields, Breidablikk, Tyrving, and Yggdrasil are given as follows in Question 4:

- Breidablikk: 107 $MtCO_2$
- Tyrving: 12 $MtCO_2$
- Yggdrasil: 365 $MtCO_2$

I have been asked to assess the consistency of these emissions with Norway's remaining carbon budget as of 2024 calculated on a per-capita basis. The IPCC presents the remaining carbon budget from the start of 2020 onwards, but the remaining carbon budget has declined substantially since then, primarily due to greenhouse gas emissions in the intervening years, and so it would be misleading to compare the emissions of these projects against (Norway's share) of an outdated remaining carbon budget. I therefore estimate Norway's remaining carbon budget from 2024 using the updated global carbon budget estimate provided in the response to question 4, above.

b. Norway's remaining carbon budget from 2024

In 2023, the last year for which population data is available at the time of writing, the population of Norway was 5.52 million, and the global population stood at 8.09 billion.[45] As such, Norway's population was approximately 0.068% of the global total. If the remaining carbon budget is allocated between states in proportion to their population (an 'equal per capita' approach), Norway's remaining carbon budget based on the remaining emissions budget at the start of 2024[41] was just 0.136 $GtCO_2$ for a 50% chance of limiting global warming to 1.5°C, as shown in Table 6. I also quantify the portion of the remaining carbon budget for Norway that would be filled by the emissions from each of the three projects and present these results in Table 6.

2024			
Likelihood of limiting global warming to within 1.5°C temperature limit	**50%**	**67%**	**83%**
Remaining global carbon budget from the beginning of 2024 ($GtCO_2$)	200	150	100
Remaining carbon budget for Norway from the beginning of 2024 ($GtCO_2$)	0.136	0.102	0.068
Breidablikk % of Norway's remaining carbon budget	78.7%	104.9%	157.4%
Tyrving % of Norway's remaining carbon budget	8.82%	11.8%	17.7%
Yggdrasil % of Norway's remaining carbon budget	268%	358%	537%

Table 6. The remaining carbon budget globally and for Norway from the start of 2024 based on Forster et al. 2024.[41] The projected emissions from each of the three projects are shown as a portion of this remaining carbon budget.

This is an overestimate of Norway's remaining carbon budget for two reasons.

- States' emissions inventories reported according to the IPCC Guidelines for National Greenhouse Gas Inventories exclude emissions from international aviation and shipping. Accounting for these emissions would further reduce the remaining carbon budget to be allocated between states.
- I use a simple, per capita, approach for allocating the remaining carbon budget between states. This does not reflect Norway's fair share of the remaining carbon budget. If Norway's historically high

contribution to global greenhouse gas emissions and capacity to decarbonise their economy were to be accounted for, it is likely that Norway's share of the remaining carbon budget would be reduced.

The emissions that would result from the extraction and expected use (including combustion) of the oil and gas expected to be produced from each of the three projects are large relative to the size of Norway's remaining carbon budget. Yggdrasil would produce emissions that are more than double the size of Norway's remaining carbon budget for a 50% likelihood of limiting warming to 1.5 °C. This analysis also shows that the emissions from the Bredablikk field alone are equal to 57% more than Norway's remaining carbon budget for an 83% chance of global temperature rise remaining below 1.5 °C above pre-industrial levels (79% and 105% of the remaining budget for a 50% and 67% chance of remaining below 1.5 °C, respectively).

Although the emissions from Breidablikk alone would take up a substantial portion of (or more than the entirety of, for a >67% chance of limiting warming to 1.5 °C) Norway's remaining carbon budget, the report 'Breidablikk: Additional report on combustion emissions' published by Equinor found that Breidablikk is only expected to contribute around 1% of Norway's total oil and gas production in the period 2023-2060.[†] Consequently, Norway's existing oil and gas fields are already projected to far exceed Norway's remaining carbon budget from 2024.

c. 2025 update to Norway's remaining carbon budget

In 2025, updated remaining carbon budget numbers have been published according to the same method as those used in the 2024 update and the IPCC's Sixth Assessment Report. The 2025 updated carbon budget numbers reveal that the remaining carbon budget has dwindled further to just 130 $GtCO_2$ for a 50% chance of limiting warming to 1.5 °C, and just 30 $GtCO_2$ for an 83% chance.[10] If the assessment of the projects' consistency with the remaining carbon budget for Norway was repeated in 2025 then the emissions associated with both the Breidablikk and Yggdrasil projects would exceed Norway's remaining carbon budget, even for only a 50% likelihood of remaining within 1.5°C of pre-industrial temperatures.

2025			
Likelihood of limiting global warming to within 1.5°C temperature limit	**50%**	**67%**	**83%**
Remaining global carbon budget from the beginning of 2024 ($GtCO_2$)	130	80	30
Remaining carbon budget for Norway from the beginning of 2024 ($GtCO_2$)	0.0884	0.0544	0.0204
Breidablikk % of Norway's remaining carbon budget	121%	197%	525%
Tyrving % of Norway's remaining carbon budget	13.6%	22.1%	58.8%
Yggdrasil % of Norway's remaining carbon budget	413%	671%	1790%

Table 7. The remaining carbon budget globally and for Norway from the start of 2025 based on Forster et al. 2025.[10] The projected emissions from each of the three projects are shown as a portion of this remaining carbon budget.

[†] Equinor (2024). 'Breidablikk: Tilleggsutredning om forbrenningsutslipp'. Available at: https://cdn.equinor.com/files/h61q9gi9/global/0dd5904b3b34efcdd6b746bf12b2dd9a90a0723f.pdf (Accessed 14/7/2025).

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