Evidence that current proven reserves of oil and gas exceed CO$_2$ budgets consistent with the Paris Agreement temperature targets

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Summary

1. South Africa has committed in its Nationally Determined Contribution to emissions reductions that are consistent with its fair share of the global reductions needed to meet the global warming limits in the Paris agreement of well below 2.0°C, ideally below 1.5°C.
2. While the net emissions that are consistent with the Paris targets have considerable uncertainties due to biogeochemical and geophysical uncertainties about the earth system, net emissions from today need to be below 400 Gt CO$_2$ to have a 50% likelihood of keeping below 1.5°C, and 800 Gt to keep “well below” 2.0°C.
3. Emissions from fossil fuels greater than 400 and 800 Gt will require substantial carbon dioxide removal (CDR) to meet the Paris temperature targets. Questions remain as to the viability of large scale CDR, especially up to 2050 when net zero emissions are required.
4. The CO$_2$ budgets for oil and gas within any overall emissions budget vary depending on assumptions on the future mix of coal, oil and gas. The least-precautionary estimates of budgets for oil and gas consistent with 1.5°C are 248 and 121 Gt CO$_2$, respectively.
5. CO$_2$ budgets that are consistent with keeping well below 2.0°C are 396 and 194 Gt CO$_2$ for oil and gas, respectively.
6. Proven reserves of oil and gas, if burned, would produce at least 543 and 350 Gt CO$_2$, respectively.
7. The emissions from burning already proven oil and gas will substantially exceed the budget available to meet the 1.5°C target.
8. Emissions of CO$_2$ from burning proven oil reserves will also substantially exceed the “well below 2.0°C” oil and gas emissions budgets.

Background context: the Paris agreement

The “Paris Agreement” is a legally binding international treaty on climate change, adopted by 196 Parties to the UNFCCC at COP 21 in Paris, on 12 December 2015 and entered into force on 4 November 2016$^1$. One of the goals of the agreement is to limit global warming to well below 2.0 degrees Celsius, preferably to 1.5 degrees, compared to pre-industrial levels. The mechanisms to achieve this goal are Nationally Determined Contributions (NDCs), where nations communicate actions they will take to reduce their greenhouse gas emissions.

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South Africa has ratified the Paris Agreement, submitted an intended NDC in 2015\(^2\), and is currently revising this for the next NDC submission in 2021\(^3\). Within the current draft of the 2021 NDC, RSA commits to emissions reductions informed by the best available science, and puts forward its “highest possible level of ambition, based on science and equity, in light of our national circumstances”. It says that the “mitigation NDC target is also informed by the Talanoa Dialogue and the IPCC special report on 1.5°C”. In essence, the country has committed - subject to international financial and technical support - to emissions reductions that will deliver RSA’s fair share to achieve the 1.5°C goal.

Greenhouse gas emissions budgets to meet the 1.5°C and 2.0°C targets

The 2018 IPCC Special Report on 1.5 Degrees (SR15)\(^4\) specifically assesses the greenhouse gas emission reduction pathways that will keep global warming below the Paris Agreement 1.5°C and 2.0°C targets.

There are a range of possible future emission pathways that meet these targets, but as a general rule the sooner global emissions peak the less steep subsequent reductions are needed. Pathways that peak late and decline slowly will either cause greater warming, possible overshooting 2.0°C, or will need carbon dioxide removal to reduce GHG concentrations to levels consistent with the 1.5°C and 2.0°C targets.

Uncertainties in carbon cycle feedbacks and climate sensitivity mean that any emissions pathway could lead to a range of possible future warming levels. Therefore, scientific literature often presents a likelihood of a particular emissions pathway meeting a given target (e.g. 50%, 66%, 90%). A higher likelihood threshold (a more precautionary approach) will reduce the allowable future emissions.

A common approach to summarising the emissions reduction challenge is to estimate a remaining CO\(_2\) budget (the cumulative total of emissions into the future) that meets the 1.5 or 2.0°C target. In 2018, the IPCC estimated that budget to be 580 Gt CO\(_2\) to have a 50% likelihood of keeping below 1.5°C, and 420 Gt CO\(_2\) for a 66% likelihood\(^4\). The budget for keeping below 2.0°C was 1500 and 1170 GtCO\(_2\) for 50% and 66% likelihoods, respectively. Given global emissions of CO\(_2\) since 2018 have been approximately 80Gt, the current remaining budget for 1.5 degrees can be adjusted down to 500 and 340 Gt CO\(_2\) (50% and 66% likelihood) and similarly, the 2.0 degrees budget to 1420 and 1090 Gt CO\(_2\). Different estimates of this budget are shown in Table 1. The latest IEA world energy outlook report adopts a budget of 500Gt for 1.5°C, based on similar logic\(^5\).

How a future CO\(_2\) budget could be distributed between different sources (coal, oil, gas, others) depends on the mix of these sources into the future. Table 1 presents estimates of


the total CO₂ budget consistent with 1.5°C and 2.0°C from the IPCC SR15 (which itself summarizes underlying literature), along with a breakdown of fossil fuel components of that budget between coal, oil and gas, under different emissions reduction scenarios in line with 1.5°C. Although IPCC does not provide a breakdown for other temperature targets, we estimate the budgets by scaling the 1.5°C budgets for the other warming targets. All scenarios assume that coal phases out more quickly than gas and oil, and the higher budgets assume significant carbon dioxide removal (CDR; see Box 1). In addition, scenarios with higher oil budgets are offset by lower gas budgets and vice versa. For oil and gas, the remaining maximum 1.5°C budgets (assuming these two energy sources are preferred to coal, and 50% likelihood) for each that do not depend on large-scale CDR are 248 and 121 Gt CO₂ respectively. The combined maximum budget across scenarios is 369 and 468 Gt CO₂, assuming minor and significant CDR, respectively.

If one adopts the recommendation of Matthews et al⁶ that the Paris target of “well below” 2.0°C equates to 1.75°C, with a likelihood of 66%, the maximum budgets for oil and gas scale to 396 and 194 Gt CO₂, without significant CDR.

Table 1. Remaining emissions of CO₂ consistent with a 1.5 and 2.0°C warming targets, from the IPCC SR15, adjusted to take account of the 80Gt CO₂ emitted up to 2020. Net emissions represent the difference between emissions and CDR. The IPCC P1-P4 scenarios show total actual emissions that deliver the net emission target, with increasing levels of CDR from P1 to P4. *Note that emissions breakdown for P1-P4 for 2.0°C and 1.75°C are estimates arrived at by scaling 1.5°C estimates by the net emissions estimate.

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<tbody>
<tr>
<td><strong>Emission Source</strong></td>
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<td><strong>Total Net Emissions</strong></td>
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<tr>
<td><strong>Emission Source</strong></td>
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<tr>
<td><strong>IPCC Scenario</strong></td>
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<tr>
<td><strong>Coal</strong></td>
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<tr>
<td><strong>Oil</strong></td>
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<td><strong>Gas</strong></td>
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(1) Current emissions from Friedlingstein (2020)⁷ as reported by Our World in Data.

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Box 1: Carbon-dioxide removal as a climate mitigation option

Carbon-dioxide removal (CDR) refers to the “process of removing CO\textsubscript{2} from the atmosphere” so as to achieve “negative emissions”\textsuperscript{8,9}. There are two broad categories of CDR, natural and artificial. Examples of natural CDR include afforestation and land restoration, where plants (especially trees) are used to take up CO\textsubscript{2} via photosynthesis and this is then stored in living plant mass and later as dead material on and within the soil. Artificial methods, called “direct air capture and carbon storage” (DACCS), use mostly yet to be proven engineered processes to capture atmospheric CO\textsubscript{2} for subsequent geological storage. A hybrid approach called “bioenergy with carbon capture and storage” (BECCS) utilises biomass for energy, capturing the CO\textsubscript{2} emissions and similarly to DACCS, storing them geologically. Land-based approaches such as afforestation and BECCS frequently will involve trade-offs with use of land for other purposes, especially food production, and their feasibility depends strongly on transformations in the global food system towards low-meat diets. The storage of CO\textsubscript{2} in BECCS and DACCS require substantial geological storage sites, and these are not always close enough to where the CO\textsubscript{2} is captured, for example at a power plant. Overall, (i) some CDR methods have been shown to be feasible, but there are doubts as to whether they can be deployed at scale without major negative side-effects; (ii) the remaining CDR methods are yet to be proven; (iii) nearly all CDR methods are expensive, at much greater than US$ 100 per tonne of CO\textsubscript{2}, adding considerably to the full cost of burning fossil fuels.

Proven reserves of coal, oil and gas, and their combustion CO\textsubscript{2} emissions

Estimates of proven fossil fuel reserves vary widely between studies, due to different definitions of what constitutes proven, how such reserves are estimated, whether conventional or unconventional sources are considered, and which geographic regions are included (e.g., OPEC versus non-OPEC; Arctic included or excluded)\textsuperscript{10}. Table 2 shows a range of estimates from different sources, summarised by McGlade and Ekins\textsuperscript{10} and other sources. The upper and lower ranges from these studies are 1,300-2,300 billion barrels of oil, 186-2,200 trillion cubic metres of gas, and 850-1,069 billion tons of coal, respectively.

The combustion emissions of CO\textsubscript{2} from different fossil fuel sources is dependent on several factors, including the characteristics of the raw resource (e.g., heavy versus light crude oil), the refining process and end product (e.g. gasoline versus diesel), and the efficiency of the eventual burning for energy. Estimates of future CO\textsubscript{2} emissions from fossil fuels are therefore dependent on assumptions about how these fuels are used. The most conservative estimates from the literature suggest that the minimum emissions from combustion of already discovered oil, gas and coal will be 543, 350 and 1,540 Gt CO\textsubscript{2}.


respectively (Table 2). If the reserves or emissions per unit fossil fuel are higher, then these values increase.

Table 2. Estimates of known global reserves of oil, gas and coal, and associated estimated emissions of CO$_2$ from their combustion (emission factors from McGlade and Ekins$^5$). Gb = billions of barrels; Tcm = trillion cubic metres; Gt = billions tonnes.

<table>
<thead>
<tr>
<th>Source</th>
<th>Oil (Gb)</th>
<th>Oil-CO$_2$ (Gt)</th>
<th>Gas (Tcm)</th>
<th>Gas-CO$_2$ (Gt)</th>
<th>Coal (Gt)</th>
<th>Coal-CO$_2$ (Gt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BGR</td>
<td>1,600</td>
<td>661</td>
<td>195</td>
<td>388</td>
<td>1,000</td>
<td>1,756</td>
</tr>
<tr>
<td>IEA</td>
<td>1,700</td>
<td>700</td>
<td>190</td>
<td>379</td>
<td>1,000</td>
<td>1,756</td>
</tr>
<tr>
<td>GEA</td>
<td>1,500-2,300</td>
<td>621-936</td>
<td>670-2,000</td>
<td>1,229-3,584</td>
<td>850-1,000</td>
<td>1,540-1,756</td>
</tr>
<tr>
<td>ME</td>
<td>1,300</td>
<td>543</td>
<td>190</td>
<td>379</td>
<td>1,000</td>
<td>1,756</td>
</tr>
<tr>
<td>HO</td>
<td>1,688</td>
<td>626.9</td>
<td>186</td>
<td>350.4</td>
<td>892</td>
<td>1,756.9</td>
</tr>
<tr>
<td>BP (2020)</td>
<td>1,734</td>
<td>644*</td>
<td>199</td>
<td>375*</td>
<td>1,069</td>
<td>2,379*</td>
</tr>
</tbody>
</table>

BGR = Federal Institute for Geosciences and Natural Resources$^{11}$; IEA = International Energy Agency$^{12}$; GEA, Global Energy Assessment$^{13}$; ME = McGlade and Ekins$^{10}$; HO = Heede & Oreskes$^{14}$ using reserve data obtained from BP (2014)$^{15}$; BP = Authors’ own calculations for emissions based on reserve data from BP (2020)$^{16}$ using the methodology reported in Heede & Oreskes$^{14}$.

Comparison of Paris CO$_2$ budgets and emissions from proven reserves

Based on the IPCC estimates of oil and gas CO$_2$ emissions budgets consistent with the more ambitious 1.5°C Paris Agreement target, the least precautionary (maximum) budget (50% likelihood of meeting target) requires net emissions of 500 Gt in total, and around 248 and 121 Gt for oil and gas, respectively. This compares to emissions from burning of the lowest estimates of proven oil and gas of 543 and 350 Gt CO$_2$, respectively. There is already sufficient proven oil to supply over double the emissions consistent with 1.5°C, while for gas, proven reserves are nearly three times the 1.5°C CO$_2$ budget.

Emissions budgets are more generous for the 2.0°C target. The least precautionary budget (2.0°C at 50% likelihood) allows for net emissions of 1420 Gt CO$_2$, of which oil and gas could make up 538-879 and 363-431 Gt (without significant CDR). However, many have argued that the Paris objective of keeping "well below 2.0°C" would require a more precautionary approach in setting these budgets, for example by choosing a 66% likelihood of keeping below 1.75°C$^6$. In this case, the net emissions budget is 800 Gt CO$_2$ in total, of which oil comprises 396 Gt CO$_2$ and gas 194 Gt CO$_2$ (without significant CDR). Therefore, emissions

of 543 and 350 Gt CO2 from burning proven oil and gas reserves would thus result in significantly exceeding this “well below 2.0°C” carbon budget for both oil and gas. It is only in the case of the least precautionary emissions scenarios, with a high risk of overshooting 2.0°C, that emissions from oil and gas are less than those from proven reserves.