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.

[1] UNFCCC (2015). Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 12, 2015, T.I.A.S. No. 16-1104, United Nations Treaty Collection.

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

[2] RSA [Government of the Republic of South Africa]. 2015. South Africa's Intended Nationally Determined Contribution (INDC). Pretoria: Government of the Republic of South Africa. https://www4.unfccc.int/sites/ndcstaging/Pub-lishedDocuments/South%20Africa%20First/South%20Africa.pdf.

[3] RSA [Government of the Republic of South Africa]. 2021. Proposed updated Nationally Determined Contribution: South Africa's first Nationally Determined Contribution under the Paris Agreement, updated 2021. https://www.environment.gov.za/sites/default/files/reports/draftnationalydeterminedcontributions_2021updated.pdf.

[4] IPCC (2018). Summary for Policymakers. Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. V. Masson-Delmotte, P. Zhai, H. O. Pörtner et al. Cambridge, United Kingdom, and New York, NY, USA, Cambridge University Press: 1-32.

[5] IEA (2021), Net Zero by 2050, IEA, Paris https://www.iea.org/reports/net-zero-by-2050

the total CO_2 budget consistent with 1.5°C and 2.0°C from the IPCC SR15 (which itself summarises 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 CO_2 respectively. The combined maximum budget across scenarios is 369 and 468 Gt CO_2, assuming minor and significant CDR, respectively.

If one adopts the recommendation of Matthews et al[6] 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 CO_2 consistent with a 1.5 and 2.0°C warming targets, from the IPCC SR15, adjusted to take account of the 80Gt CO_2 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.*

	Current Emissions (1)	**Emission Budget for Temperature Target / Likelihood of Meeting Target (Gt CO2)**					
Emission Source	2019	1.5°C / 50%	1.5°C / 66%	1.75 / 50%	1.75 / 66%	2.0°C / 50%	2.0°C / 66%
Total Net Emissions	36.45	500	340	1040	800	1420	1090
IPCC Scenario		*P1 P2 P3 P4*	*P2* P4**	*P1* P2* P3* P4**	*P2* P4**	*P1* P2* P3* P4**	*P2* P4**
Coal	14.36 (39.4%)	63 139 105 116	43 71	132 288 219 242	222 186	225 492 373 413	302 253
Oil	12.36 (33.9%)	152 248 235 491	103 160	315 515 489 1022	396 786	538 879 835 1745	540 1071
Gas	7.62 (20.9%)	102 121 233 195	70 159	213 253 485 406	194 313	363 431 828 694	265 426

(1) Current emissions from Friedlingstein (2020)[7] as reported by Our World in Data

[6] Matthews, H.D., Tokarska, K.B., Nicholls, Z.R.J. et al. Opportunities and challenges in using remaining carbon budgets to guide climate policy. Nat. Geosci. 13, 769–779 (2020). https://doi.org/10.1038/s41561-020-00663-3.
[7] Friedlingstein, P., et al., (2020). Global carbon budget 2020. *Earth System Science Data*, *12*(4), pp.3269-3340.

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

Carbon-dioxide removal (CDR) refers to the "process of removing CO_2 from the atmosphere" so as to achieve "negative emissions"[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_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_2 for subsequent geological storage. A hybrid approach called "bioenergy with carbon capture and storage" (BECCS) utilises biomass for energy, capturing the CO_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_2 in BECCS and DACCS require substantial geological storage sites, and these are not always close enough to where the CO_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_2, adding considerably to the full cost of burning fossil fuels.

Proven reserves of coal, oil and gas, and their combustion CO_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)[10]. Table 2 shows a range of estimates from different sources, summarised by McGlade and Ekins[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_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_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_2

[8] IPCC (2018). FAQ 4.2 What are Carbon Dioxide Removal and Negative Emissions? In: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* Eds: V. Masson-Delmotte, et al Cambridge, United Kingdom, and New York, NY, USA, Cambridge University Press: 1-32.

[9] Royal Society and Royal Academy of Engineering (2018). Greenhouse Gas Removal Policy briefing DES5563_1. https://royalsociety.org/topics-policy/projects/greenhouse-gas-removal.

[10] McGlade, C. and Ekins, P. (2015) The geographical distribution of fossil fuels unused when limiting global warming to 2 °C. *Nature,* 517, 187–190. https://doi.org/10.1038/nature14016.

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.

Source	Oil (Gb)	Oil-CO_2 (Gt)	Gas (Tcm)	Gas-CO_2 (Gt)	Coal (Gt)	Coal-CO_2 (Gt)
BGR	1,600	661	195	388	1,000	1,756
IEA	1,700	700	190	379	1,000	1,756
GEA	1,500-2,300	621- 936	670-2,000	1,229-3,584	850-1,000	1,540-1,756
ME	1,300	543	190	379	1,000	1,756
HO	1,688	626.9	186	350.4	892	1,756.9
BP (2020)	1,734	644*	199	375*	1,069	2,379*

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

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11 Federal Institute for Geosciences and Natural Resources (BGR). Energy Study 2012. Reserves, Resources and Availability of Energy Resources. http://www.bgr.bund.de/DE/Gemeinsames/Produkte/Downloads/DERA_Rohstoffinformationen.

12 International Energy Agency (IEA) (2013). World Energy Outlook. http://www. worldenergyoutlook.org/publications/weo-2013.

13 Rogner, H.-H. et al. (2021) in: Global Energy Assessment —Towards a Sustainable Future. Ch. 7, 423–512, Cambridge University Press.

14 Heede, R. and Oreskes, N. (2016). Potential emissions of CO2 and methane from proved reserves of fossil fuels: An alternative analysis. *Global Environmental Change*, *36*, pp.12-20.

15 BP (2014 & 2013). Statistical Review of World Energy. London, www.bp.com/statisticalreview.

16 BP (2020). Statistical Review of World Energy. London, www.bp.com/statisticalreview.

of 543 and 350 Gt CO_2 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.