Article

Unextractable fossil fuels in a 1.5 °C world

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Parties to the 2015 Paris Agreement pledged to limit global warming to well below 2 °C and to pursue efforts to limit the temperature increase to 1.5 °C relative to pre-industrial times[1]. However, fossil fuels continue to dominate the global energy system and a sharp decline in their use must be realized to keep the temperature increase below 1.5 °C (refs. [2–7]). Here we use a global energy systems model[8] to assess the amount of fossil fuels that would need to be left in the ground, regionally and globally, to allow for a 50 per cent probability of limiting warming to 1.5 °C. By 2050, we find that nearly 60 per cent of oil and fossil methane gas, and 90 per cent of coal must remain unextracted to keep within a 1.5 °C carbon budget. This is a large increase in the unextractable estimates for a 2 °C carbon budget[9], particularly for oil, for which an additional 25 per cent of reserves must remain unextracted. Furthermore, we estimate that oil and gas production must decline globally by 3 per cent each year until 2050. This implies that most regions must reach peak production now or during the next decade, rendering many operational and planned fossil fuel projects unviable. We probably present an underestimate of the production changes required, because a greater than 50 per cent probability of limiting warming to 1.5 °C requires more carbon to stay in the ground and because of uncertainties around the timely deployment of negative emission technologies at scale.

In 2015, McGlade and Ekins[9] set out the limits to fossil fuel extraction under stringent climate targets. They estimated that one-third of oil reserves, almost half of fossil methane gas reserves and over 80% of current coal reserves should remain in the ground in 2050 to limit warming to 2 °C. They also highlighted that some countries would need to leave much higher proportions of fossil fuel reserves in the ground than others. Since 2015, the Paris Agreement and the Intergovernmental Panel on Climate Change (IPCC) have helped to refocus the debate on warming limits of 1.5 °C (refs. [1,10]). Multiple scenarios have been published, showing the additional effort required to limit global CO_2 emissions to net zero by around 2050 to meet this target[11]. In this Article, we extend the earlier 2015 work to estimate the levels of unextractable fossil fuel reserves out to 2100 under a 1.5 °C scenario (50% probability), using a 2018–2100 carbon budget of 580 $GtCO_2$ (ref. [3]). We also provide insights into the required decline of fossil fuel production at a regional level, which will necessitate a range of policy interventions. We define unextractable fossil fuels as the volumes that need to stay in the ground, regardless of end use (that is, combusted or non-combusted), to keep within our 1.5 °C carbon budget.

Paris Agreement-compliant fossil fuel prospects

Fossil fuels continue to dominate the global energy system, accounting for 81% of primary energy demand[12]. After decades of growth, their rate of production and use will need to reverse and decline rapidly to meet internationally agreed climate goals. There are some promising signs, with global coal production peaking in 2013, and oil output estimated to have peaked in 2019 or be nearing peak demand, even by some industry commentators[13].

The plateauing of production and subsequent decline will mean that large amounts of fossil fuel reserves, prospects that are seen today as economic, will never be extracted. This has important implications for producers who may be banking on monetizing those reserves in the future, and current and prospective investors. Investments made today in fossil fuel energy therefore risk being stranded[14]. However, there continues to be a disconnect between the production outlook of different countries and corporate entities and the necessary pathway to limit average temperature increases[2].

A number of analyses have explored how fossil fuels fit into an energy system under a 1.5 °C target. The IPCC's *Special Report on Global Warming of 1.5 °C* estimates coal use only representing 1–7% of primary energy use in 2050, while oil and fossil methane gas see declines relative to 2020 levels by 39–77% and 13–62%, respectively[3]. Despite strong declines, the use of fossil fuels continues at lower levels, reflecting the assumed inertia in the system and continued use of fossil fuels in hard-to-mitigate sectors. Luderer et al.[4] estimate that, despite large-scale efforts, CO_2 emissions from fossil fuels will probably exceed the 1.5 °C carbon budget and require high levels of carbon dioxide removals (CDR). Grubler et al.[5] explored efforts to reduce energy demand, substantially reducing the role of fossil fuels and removing the need for CDR deployment.

The extent of fossil fuel decline in the coming decades remains uncertain, influenced by factors such as the rapidity of the rollout of clean technologies and decisions about the retirement of (and new investment in) fossil fuel infrastructure. Indeed, while dependent on lifetimes and operating patterns, existing fossil fuel infrastructure already places a 1.5 °C target at risk owing to implied 'committed' future CO_2 emissions[6]. The possible extent of CDR further complicates this

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