Given all this, what is to be said about the near-term prospects for BECCS? The models giving rise to the aforementioned projections of BECCS deployment are useful for assessing potential mixes of future generation technology and identification of potential trade-offs between different mitigation strategies. They are also useful for spurring conversations about the need for severe measures to meet climate mitigation objectives and about the potential viability of particular pathways. In the case of BECCS, however, those conversations have struggled to grapple with the social, economic and political barriers to deployment. These observations are not new, but the magnitude of the challenge is only slowly finding its way to the forefront of the dialogue[13].

If we assume that BECCS will play a substantial part in meeting future GHG reduction objectives, there is a need for a broader dialogue around deployment. First and foremost, there must be agreement on the net GHG benefits of BECCS and how to account for them. Second, there must be sufficient governance of the potential co-effects associated with scaling the technology, particularly elements of water consumption, biodiversity impacts and food production. Third, there must be greater awareness of the barriers to siting supportive infrastructure such as pipelines to facilitate the use of otherwise available biomass and storage resources. Notably, all three of these elements fall outside the realm of traditional IAM analyses and speak to the need to involve a wider community of scholars and practitioners. This is particularly salient given recent analysis suggesting that BECCS research involves a relatively narrow subset of the academic community[14].

Alternatively, if we consider that BECCS will be unable to overcome the challenges identified above and will instead become a “largely niche technology applied in industrial processes in a world dominated by renewables and other non-fossil energy sources” (ref. [8], p. 335), then consideration must be given to the expected size of its contribution to GHG mitigation. Future capacity need not be zero, and research suggests that BECCS may have greatest potential in contexts where there is already familiarity with its constituent elements[12]. For example, US ethanol production could yield approximately 19–30 $MtCO_2e$ of captured, transported and stored emissions annually, depending on pipeline financing arrangement[15]. But this is far below the average annual mitigation necessary to generate median-level projections of reductions attributable to BECCS in the United States, estimated to be approximately 7.5 $GtCO_2e$ between 2020 and 2050[4], or roughly 250 $MtCO_2e$ annually. To reach these levels would require not only the contributions from low-cost ethanol refineries, but also the capture of emissions from nearly all existing wood, wood-derived and biomass waste biopower capacity.

If BECCS cannot achieve the mitigation it has been tasked with, something else must take up the slack. Although such strategies may be suboptimal from a modelling perspective, it is imperative that we confront them fully, given the challenges associated with otherwise preferred solutions such as BECCS. Regardless of the path forward, the current situation speaks to the need for a broader dialogue, a dialogue that thus far has largely failed to materialize. ❐

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Carbon dioxide emissions continue to grow amidst slowly emerging climate policies

A failure to recognize the factors behind continued emissions growth could limit the world’s ability to shift to a pathway consistent with 1.5 °C or 2 °C of global warming. Continued support for low-carbon technologies needs to be combined with policies directed at phasing out the use of fossil fuels.

G. P. Peters, R. M. Andrew, J. G. Canadell, P. Friedlingstein, R. B. Jackson, J. I. Korsbakken, C. Le Quéré and A. Peregon

Global fossil CO_2 emissions grew at 0.9% per year in the 1990s and accelerated to 3.0% per year in the 2000s, but have returned to a slower growth rate of 0.9% per year since 2010, with a more pronounced slowdown from 2014 to 2016. Despite modest declines in emissions in the United States and the European Union (EU) over the past decade, the growth in emissions in China, India and most developing countries has dominated global emission trends over the past 20 years. The Global Carbon Budget projection[1] suggests that global fossil CO_2 emissions will grow by 0.6% (range –0.2% to 1.5%) in 2019, with emissions projected to decline in the United States and the EU28, but projected to increase in China, India and the rest of the world (Fig. 1a).

Although a focus on countries and regions is important, a focus on type of fossil fuels and key emitting sectors is particularly relevant for monitoring changes and implementing adequate mitigation policies. Globally, over the past decade (2009–2018), 42% of fossil CO_2 emissions were from coal, 34% from oil, 19% from natural gas, and the remaining 5% from cement and other smaller sources (Fig. 1b). In 2019, CO_2 emissions from coal are projected to decline by 0.9%, with substantial drops in emissions from coal use in the United States (–10%) and the EU28 (–10%), and weak growth in China and India due to economic and weather anomalies. Oil is projected to grow by 0.9% in 2019 and natural gas by 2.6%, both in line with growth over the past 10 years.

At the most aggregated level, over the past decade, 45% of fossil CO_2 emissions come from the energy sector, dominated by electricity and heat production. Industry sectors, such as metals production, chemicals and manufacturing, cover 23% of global emissions. Land transport combined with national shipping and aviation contributes 19% of global emissions, while international shipping and aviation add another 3.5%. The remaining 10% is from buildings, agriculture, fishing and other sectors not elsewhere covered (for example military). In the following, we detail key changes in fossil CO_2 emissions across these sectors for the different fossil fuels: coal, oil and gas.

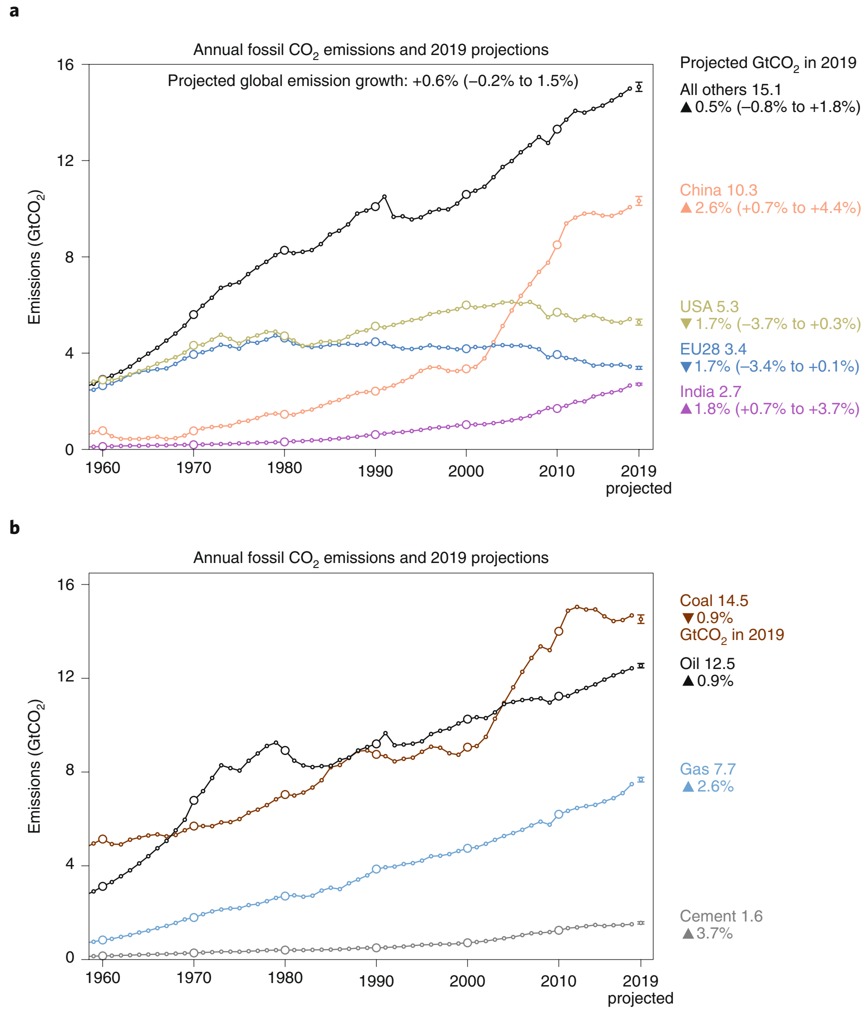

Fig. 1 | Global fossil CO_2 emissions showing projections for 2019. Projections are from ref. [1]. **a**, Emissions and projections for regions. **b**, Emissions and projections for fossil fuels and cement. The projections for China, the United States, EU28 and India in 2019 are based on monthly data available at the time of submission; all others are based on economic data. The projections are done separately for coal, oil, gas and cement in each region. The Indian projection is based on the Indian financial year, April 2019 to March 2020. Both China and India exhibit higher uncertainty than usual because of unusual economic (China and India) and monsoon (India) events. Error bars indicate $\pm 1\sigma$.

Coal is still king, but losing power

The changes in global emissions have primarily been driven by changes in coal use, whereas growth in the use of oil and gas has continued unabated since 1980 following the oil crises in the 1970s (Fig. 2a). Many analysts have speculated that coal use may have peaked. The decline in coal use in Organisation for Economic Co-operation and Development (OECD) countries is clear, with a 25% drop in the past decade. Growth in coal use in non-OECD countries has remained strong but is heavily influenced by China. A global peak in coal use is highly dependent on the pathway in China, which now accounts for 50% of its global use. Although changes in the structure of China's economy may have contributed to a recent decline in coal use[2], Chinese emissions are rising again, and it is too early to proclaim a coal peak in China or globally[1].

The remarkable shifts in coal use have occurred in different sectors (Fig. 2a). The largest share of global coal use is for electricity and heat (66%), followed by industry such as metals, chemicals and manufacturing (27%). The levelling off in global coal use in the 1990s resulted largely from the collapse of the Soviet Union[3] but was partially offset by strong growth in electricity and industry in China and India. The recent modest decline in global use has primarily occurred because of continued declines in coal power in the United States and EU, and a slowdown in coal power growth in China, combined with a slowdown in the growth in industrial production in China. The declines in electricity generation probably represent a more systematic structural change, with electricity generation from coal being replaced by non-fossil energy sources or with natural gas. The recent decline in coal use by industry may represent the effects of economic headwinds in China, as there are very few technologies to guarantee declines in the hard-to-mitigate industrial sectors[4].

Oil shows resilient growth

Global oil use has grown almost unimpeded for several decades (Fig. 2b), with the main disruptions occurring during the oil crises[3] in 1973 and 1979. The oil crises primarily hit oil use in OECD countries, but more so in sectors where oil was used inefficiently

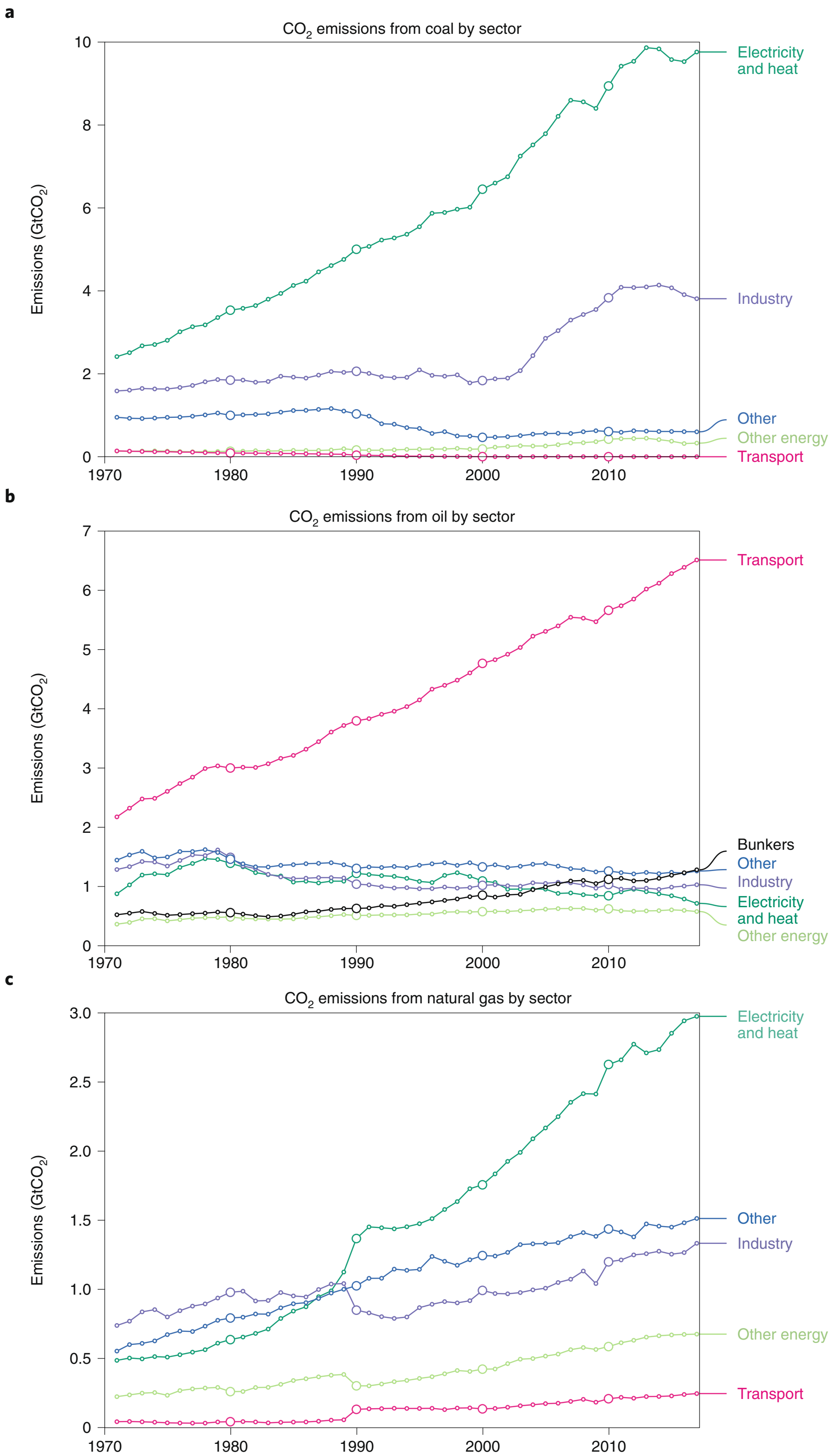

Fig. 2 | Carbon dioxide emissions from different fossil fuels by sector. a, Coal; **b**, oil; **c**, natural gas. 'Bunkers' indicates emissions from bunker fuels used in international aviation and shipping. 'Transport' indicates land transport along with domestic aviation and shipping. Source: IEA[15], based on detailed data on energy demand and IPCC Guidelines.

(electricity and industry), with limited effects in transport (Fig. 2b). Global oil use is dominated by road transport, representing 50% of emissions from oil use and growing at 1.9% per year (104 $MtCO_2$ per year) in the past decade. Oil use in OECD countries declined after the global financial crisis in 2009 but has since begun to rise again, making its current use similar to the levels in 2009. Oil use in non-OECD countries continues to grow strongly, despite a slowdown in the growth rate in the past few years. National and international aviation represents around 8% of the emissions from oil use and has been growing at around 3% per year (25 $MtCO_2$ per year) for the past decade. Other sectors (industry, power, other) are flat at the global level, with declines in OECD countries offset by increases in non-OECD countries.

Although aviation is receiving increased public attention, the continued growth in emissions from road transport is far more significant in aggregate terms and is the main driver of CO_2 emissions from oil globally. The deployment of electric vehicles is promising, but demand for transport services is growing more rapidly. In many markets, electric vehicles are adding to demand and not replacing existing vehicles, therefore having minimal effect on oil use. If electrical grids are not decarbonized fast enough, then the addition of electric vehicles may partly shift emissions from transport to the energy sector. Oil is generally an inefficient energy source outside of transport, suggesting that there are many opportunities to reduce oil use in the power sector and industry.

Natural gas is only a temporary fix

Carbon dioxide emissions from natural gas use have been growing steadily and almost uninterrupted for over half a century, and they are currently the fastest-growing source of fossil fuel emissions (Fig. 2c). Natural gas has contributed to the largest increase in global fossil CO_2 emissions in recent times, accounting for around 35% of the growth in the past decade and over 50% in the past few years. Its use is growing strongly in most countries, with the 44% of gas use in electricity and heat growing the most rapidly globally. OECD countries generally have more diverse usage of gas, with substantial use in industry, energy and buildings. Non-OECD gas use is more concentrated in the electricity sector.

Natural gas has been portrayed as a bridge fuel from coal power to non-fossil power generation because it emits about 40% less CO_2 than coal per unit of energy and can therefore reduce emissions if gas substitutes for coal in electricity generation.

Although natural gas can help to begin decarbonization in electricity generation, it still emits CO_2, and its use without carbon capture and storage (CCS) needs to be phased out not long after it displaces coal use. In some instances, natural gas could lead to worse outcomes for the climate than coal, depending on methane leakage rates[5]. Natural gas is also an attractive alternative in industrial, commercial and residential applications, but without CCS, the emissions still contribute significantly to global warming.

Although natural gas may be necessary to aid a transition from coal to non-fossil energy in some national circumstances, expanded use of natural gas without CCS could limit the ability to meet ambitious climate targets. The rapidly growing global market in liquefied natural gas will support the expansion and reach of natural gas in the coming decades, while plans to develop CCS that could limit the climate impacts of natural gas are still lagging at the small-scale demonstration stage.

Shift focus to fossil fuels

The continued growth in global fossil CO_2 emissions is taking place despite growing public and policy attention, five cycles of IPCC Assessment Reports and almost 30 years of international climate negotiations. Although some climate policies have fallen into place, leading to rapid progress in the deployment of clean energy technologies, few policies are in place to phase out fossil fuel technologies in parallel, and CO_2 emissions continue to grow globally. Even following the apparent policy breakthrough leading to the Paris Agreement in 2015, it is likely that global fossil CO_2 emissions will have grown by more than 4% through to the end of 2019. Current national policies still put the world on a pathway of increasing greenhouse gas emissions through to 2030[6].

The continued growth in fossil fuel use and associated CO_2 emissions is happening despite considerable progress in low-carbon technologies[7] and progress in some countries in reducing energy use[8]. Growth in energy use and emissions is dominated by developing countries, as they strive to close the large disparity between their per capita energy and that in developed countries[9]. This suggests that current policies are not enough to affect global emissions, or are slow to have a detectable effect, or simply fail to directly address the root cause of the problem: phasing out CO_2 emissions from the use of fossil fuels[10]. The rapid growth in solar and wind energy will help to reduce the use of coal in power generation, but current policies to phase out coal use are focused in countries with old coal fleets[11,12]. Natural gas may displace some coal in power generation, but it offers at best a short-term solution, as once coal is displaced the CO_2 emissions continue, albeit at a lower rate. The rapid growth in electric vehicles has been insufficient to alter global oil use, as the growth in transport demand far outpaces the deployment of electric vehicles. Very little attention has been paid to the difficult-to-mitigate sectors[4], such as industry, aviation and shipping, and a complete decarbonization of electricity generation.

The failure to mitigate global emissions, despite positive progress on so many aspects of climate policy, suggests that the full bag of policy options is not being effectively deployed. Most policies tend to focus on supporting low-carbon alternatives, such as solar, wind, or electric vehicles, but these technologies often add to existing demand and therefore do not displace fossil fuel use to any great extent[13]. Public policies need to place far more importance on directly cutting back the use of fossil fuels or removing their emissions through CCS, particularly the phasing out of coal power plants[14] and conventional vehicles, well before they reach their productive end-of-life. ❐

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