Mitigation on methadone: how negative emissions lock in our high-carbon addiction

In December 2015 member states of the United Nations Framework Convention on Climate Change (UNFCCC) adopted the final text of the Paris Agreement, a principal aim of which is to hold *"the increase in the global average temperature to well below 2°C"* and *"to pursue efforts to limit the temperature increase to 1.5°C"*. The Agreement also requires "*a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century*", and since some non-zero sources are unavoidable, this leads to the abstract concept of 'negative emissions'.

Carbon budgets

To understand the implications of the Paris Agreement for mitigation policy, the qualitative language of *"well below 2°C"* and *"limit…to 1.5°C"* can be translated into quantitative carbon budgets, specifying how much carbon dioxide can be emitted across the century to respect a given temperature level (*1*). Because of uncertainties in the climate system, such budgets are specified with quantitative likelihoods.

Borrowing from the IPCC's taxonomy of likelihoods, the most generous interpretation of the Paris Agreement's *"well below 2°C"* is at least a *"likely"* (66-100%) chance of not exceeding 2°C. Of the 900 mitigation scenarios from about 30 Integrated Assessment Models (IAMs) assessed by the IPCC (*2*), 76 scenarios from five IAMs had sufficient data to estimate the carbon budget for a *likely* chance of not exceeding 2°C. These scenarios give a carbon budget of between 600 and 1200GtCO_2 (10-90% range) for the period 2016 until the peak in temperature (updated from (*1*)). Increasing the likelihood of keeping temperatures below 2°C, or shifting to 1.5°C, will decrease still further the available carbon budget (*3*). The budget is also subject to an annual reduction of around 40GtCO_2 each year due to continued fossil fuel, industry, and land-use change emissions (*4*).

Despite their intuitive appeal, carbon budgets have several layers of complexity making it impossible to assign a unique budget to a given temperature rise (*5*). Assumptions on future non-CO_2 emissions affect significantly the available CO_2-only budgets. The dominance of a limited number of IAMs used to estimate carbon budgets means that the future scenario space is not exhaustively explored and there is limited model diversity (*6*). Consequently, though carbon budgets provide a valuable guide to the scale of the mitigation challenge, they cannot give a precise constraint on how much carbon can be emitted to avoid a specific and probabilistically defined temperature rise.

From carbon budgets to emission pathways

Any given carbon budget is consistent with a wide range of potential emission pathways (*2*). The 76 scenarios consistent with a *likely* chance of not exceeding 2°C exhibit a range of key characteristics (Figure 1). Two features are immediately striking.

First, the dominant presumption that the large-scale roll out of 'negative emission technologies' is technically (*2*), economically (*2*), and socially (*7*) viable. In many of the scenarios the level of negative emissions is comparable in size to the remaining carbon budget (Figure 1), and are sufficient to bring global emissions to at least net-zero in the second half of the century.

Second, there is a large and growing deviation between current emission trends and emission scenarios. The sum of the national emission pledges submitted to the Paris negotiations (COP21) lead to an increase in emissions, broadening the gap with pathways consistent with the Paris Agreement (*8*) and requiring the need for either much more severe near-term mitigation(*9*) or additional future negative emissions.

It is not well understood by policy makers (*10*), or indeed many academics, that IAMs assume such a massive deployment of negative emission technologies. Yet when it comes to the more stringent Paris obligations, studies suggest that it is not possible to reach 1.5°C with a 50% chance without significant negative emissions (*3*). Even for 2°C, very few scenarios have explored mitigation without negative emissions (*2*), and contrary to common perception, negative emissions are also prevalent in higher stabilisation targets (Figure 2) (*11*). Given such a pervasive and pivotal role of negative emissions in mitigation scenarios, their almost complete absence from climate policy discussions is disturbing and needs to be addressed urgently (*12*).

Negative Emission Technologies (NETs)

Negative Emission Technologies (NETs) exist at various levels of development (*13-16*). Afforestation (and reforestation), though not strictly a technology, is already claimed by countries as a mitigation measure (*17*). Bioenergy, in combination with carbon capture and storage (BECCS), is the most prolific NET included within IAMs and is used widely in emission scenarios. It has the unique feature of providing energy (via biomass combustion) and, in principle (*18*), removing CO_2 from the atmosphere to provide a claimed economic benefit (assuming carbon is valued) which may offset, at least in part, the additional costs of using the technology (*19*) . The carbon is assumed to be fully absorbed during biomass growth, and is captured pre- or post-combustion and then stored underground indefinitely. Despite the prevalence of BECCS within emission scenarios, at a level much higher than afforestation, only one large-scale demonstration plant exists today.

Other NETs have not yet moved beyond theory or small-scale demonstrations. Alternative and adjusted agricultural practices, including biochar, can increase the carbon uptake in soils (*14*) (Smith 2016), and a variety of countries have already proposed these as policy measures. It is possible to use direct air capture to remove CO_2 from the atmosphere via chemical reactions, with subsequent storage similar to CCS. Enhancing the natural weathering of minerals (rocks) is able to store carbon in soils, land, or oceans. Natural carbon uptake in the ocean can, potentially, be increased through the introduction of biological or chemical catalysts. It is also possible new technologies, designs and refinements will emerge over time, though caution must be exercised as to the timeframe for such novel technologies to reach maturity and subsequently be rolled out at scale.

BECCS: a political panacea

The allure of BECCS, and other NETs, stems from their promise of much reduced political and economic challenges today, compensated by speculative technologies tomorrow. Given the huge opportunities for near-term, rapid and deep reductions in energy demand at little cost (technical and behavioural), alongside ongoing cost declines in many renewable energy technologies, it is understandable that concerns arise as to why BECCS is used so prolifically in emission scenarios.

The answer is simple. Integrated assessment models apply discount rates, often have perfect foresight, and typically find that large-scale BECCS pathways are cost-optimal solutions over the 21st century. In effect, the discounted cost of BECCS in future decades is less than the cost of deep mitigation today. In postponing the need for rapid and immediate mitigation, BECCS licences the ongoing combustion of fossil fuels whilst still, ostensibly, fulfilling the Paris commitments. What's not to like?

Technically, BECCS simply combines bioenergy with CCS. In practice, both of these key components face major and perhaps insurmountable obstacles. Two decades of research and several pilot plants have struggled to demonstrate the technical and economic viability of power generation with CCS, even when combusting relatively homogeneous fossil fuels (*20*). Substituting for heterogeneous biomass feedstock adds to the already considerable challenges. Moreover, the sheer scale of biomass used in IAMs informing government policy raises profound questions (*15*) about carbon neutrality, land availability, competition with food and competing demands for bioenergy from the transport, heating and industrial sectors. Beyond this, the logistics of collating and transporting quantities of bioenergy, equivalent in energy value of up to half of total global primary energy consumption, is seldom addressed. While some studies suggest BECCS pathways are feasible, at least locally (*19*), the broader literature points to global scale limitations (*15*). Given the existing struggles of CCS and the continuing uncertainty about large-scale bioenergy, BECCS remains a highly speculative technology.

Whilst all NETs are subject to a myriad of scientific and political uncertainties, BECCS has come to dominate the scenario landscape. However, as recognition of the ubiquitous role of BECCS has grown so have concerns about the efficacy of the sheer scale of deployment assumed (*15*). Land use impacts alone have been linked to a loss of terrestrial species greater than a 2.8°C temperature rise (*14*), leading to difficult trade-offs between biodiversity loss and temperature rise. There is also a dearth of detailed and robust analysis examining the trade-offs between large-scale deployment of BECCS (and all NETs) and the broader Sustainable Development Goals (SDGs). Such a level of circumspection is, however, far removed from the technical utopia informing the IAMs. Despite BECCS continuing to stumble through its infancy, many of scenarios assessed by the IPCC propose its mature and large-scale roll out as soon as 2030 (Figure 1).

Moral hazard and intergenerational inequity

Ultimately, the appropriateness or otherwise of relying, in significant part, on NETs to realise the Paris commitments is an issue of risk (*11*). However, the distribution of this risk is highly inequitable, with the potential failure of NETs to deliver at the scale enshrined in many IAMs being felt most by those low-emitting communities who are geographically and financially vulnerable to a rapidly changing climate.

If NETs follow the idealised and rapid deployment assumed in the IAMs, and provided earth system feedbacks are reasonably linear, any reduction in near-term mitigation incentivised by future NETs will likely see only an incremental overshoot in temperature (*3*). In stark contrast, if the many reservations increasingly voiced about NETs (and significantly BECCS) turn out to be an accurate reflection of reality, the weakening of near-term mitigation and the failure of future NETs will be a prelude to rapid temperature rises reminiscent of the 4°C pre-Paris pathways (*8*).

NETs are not an insurance policy, but instead are much more akin to an unjust and high stakes gamble. There is a very real risk they will be unable to deliver on the scale of their promise. Consequently, if the emphasis on equity and the risk averse sentiment embodied in the Paris Agreement's *"well below 2°C"* and *"pursue … 1.5°C"* commitments are to have any traction, NETs should not form the basis of the mitigation agenda. This is not to say that they should be abandoned(*20, 21*), but that whilst they could very reasonably be the subject of serious research, development and potentially deployment, the mitigation agenda should proceed on the premise that they will not work at scale. The asymmetric implications of failing to do otherwise is a 'moral hazard' *par excellence.*

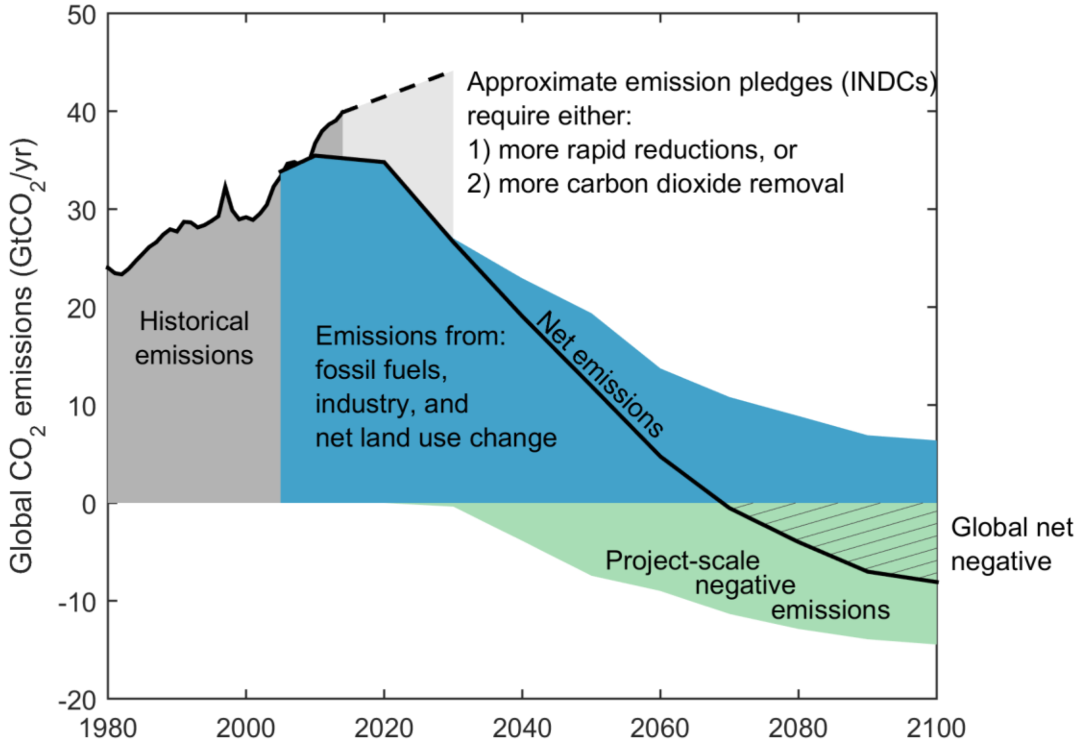

Figure 1: The median of the 76 scenarios used to estimate the 2°C with 66% likelihood carbon budget showing project-scale and global negative emissions, compared to current emission trends and projections. The project-scale negative emissions (green) start around 2030, but do not overcome emissions (blue) to become net negative emissions globally (green hatch) until about 2070. Current emissions (dark grey) and projections based on the Intended Nationally Determined Contributions (INDCs, light grey) use a sizeable part of the carbon budget requiring more rapid emission reductions or more project-scale negative emissions than in existing scenarios. Project-scale negative emissions are estimated by converting the BECCS energy consumption (EJ/yr) using an average emission factor of 100tCO_2/TJ and assuming 90% of the CO_2 is captured. The emission pledges (INDCs) in 2030 are estimated based on our 2011 emission estimates and the cumulative emissions in Rogelj et al (8).

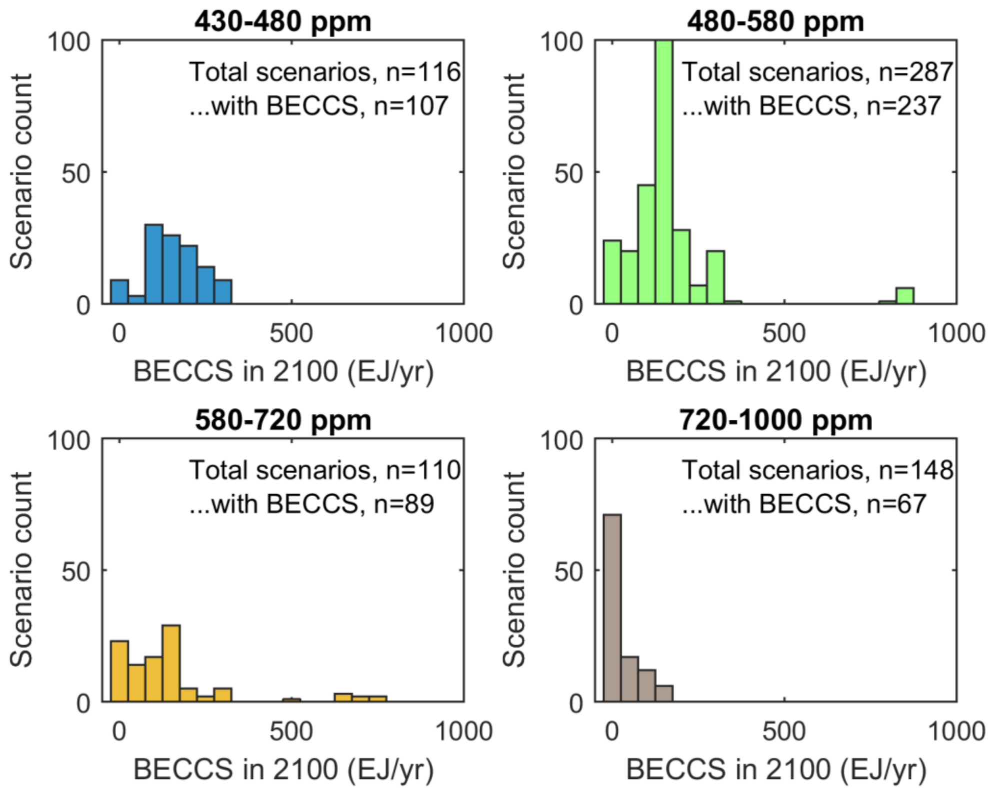

Figure 2: BECCS is not only used in 2°C scenarios (430-480ppm), but is used at scale in all mitigation pathways. In fact, the scale of BECCS can be larger when temperatures exceed 2°C. All data from the IPCC scenario database (3).

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