

The risky promise of ‘negative emissions’: Why we should not assume that land-based measures will save the climate

The Paris Agreement calls for holding global average temperature increase to “well below” 2°C, and to “pursue efforts” to limit the temperature increase to 1.5°C. Given the slow pace of action to date, there is increasing interest in “negative emissions” – measures that remove carbon from the atmosphere. The idea is to “undo” past emissions to make up for lost time and insufficient effort in the near term.

The most widely discussed options are large-scale afforestation, and bioenergy in combination with carbon capture and storage (BECCS). Landscape restoration – both restoration of closed canopy forests, and “mosaic” restoration of more intensively used landscapes – could also contribute to climate goals. (Other ideas, such as direct air capture or ocean fertilization, remain in the realm of speculation.)

This policy brief, based on an SEI working paper, examines the potential for land-based measures to achieve the expected negative emissions; the risks associated with counting on negative emissions, and what these risks mean for near-term actions and long-term mitigation strategies.

Risks of negative emission options

Increasingly, models used to study possible mitigation pathways assume that negative emission options will be available at a large scale. Not surprisingly, they find that relying on negative emission options in the comfortably distant future reduces near-term mitigation costs. In the real world, however, this “easier and less expensive” strategy poses fundamental risks, as a growing number of climate scientists have noted.

We highlight three sequential risks, summarized in Figure 1:

Risk type 1: Technological and biophysical feasibility

First, the measures on which negative emission strategies tend to rely most heavily are as yet unproven at the implied scales, and may yet prove technologically infeasible or limited by fundamental biophysical constraints.



A plantation of fast-growing eucalyptus grandis at Hamakua Coast, Hawaii.

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Key findings

- Models of climate change mitigation pathways increasingly assume large amounts of “negative emissions” – measures that pull carbon out of the atmosphere – usually deployed several decades from now. Many assume negative emissions as high as 1,000 Gt CO₂ to keep warming below 1.5°C or 2°C.
- Counting on negative emissions carries three significant risks: (i) that negative emission options will not ultimately prove feasible; (ii) that their large-scale deployment involves unacceptable ecological and social impacts; and, (iii) that negative emissions activities prove less effective than hoped, either because they are subsequently reversed by human or natural forces, or because climate change impacts prove irreversible.
- Although many models anticipate significant negative emissions from land-based measures such as forest plantations and especially bioenergy with carbon capture and storage (BECCS), our analysis suggests that only 370–480 Gt CO₂ of negative emissions could be achieved without exceeding biophysical constraints, through forest restoration and reforestation. Even that would be extremely challenging to achieve, however, and would require large amounts of land that might otherwise be used for food production.
- A review of modelled mitigation pathways suggests that the goal of limiting warming to 2°C or 1.5°C can still be achieved without excessive reliance on negative emissions. This would require immediate global mitigation on a scale that greatly exceeds that which was pledged by nations under the Paris Agreement, as well as protecting land carbon stocks by reversing forest loss and allowing degraded forests to recover.

The main technological uncertainties apply to BECCS, which has not yet been proven at a commercial scale. There are logistical challenges in securing a long-term, reliable supply of biomass feedstock to a large-scale industrial facility, integrating disparate technological systems, and establishing sufficient and spatially appropriate CCS capture, pipeline, storage infrastructure and reservoir capacity, for instance.

In addition to technological constraints, there are biophysical limits to how much carbon can be stored in the biosphere (sink saturation). Net primary production (NPP) from plant growth also limits the rate of removal of carbon from the atmosphere. BECCS is not subject to limits of sink saturation, because the carbon is sequestered in geological reservoirs. However, it relies on large-scale biomass feedstock supply, which is limited by NPP, discussed further below.

Risk type 2: Unacceptable social and ecological impacts

Even if negative emission options prove to be technically feasible, society may find the ecological and social costs to be unacceptably high, with potentially major adverse impacts on biodiversity, food security, water resources, and human rights.

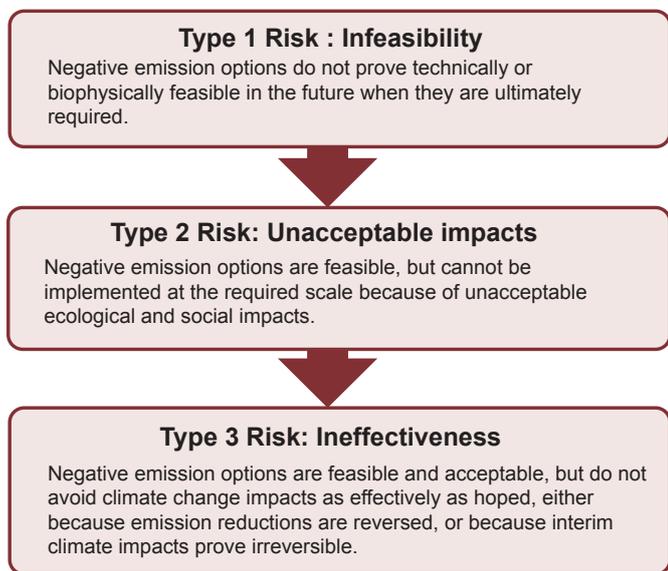


Figure 1: Three types of risks posed by negative emission measures

Land-based negative emissions options rely on biological carbon fixation, and are inherently land-intensive. Mitigation scenarios that rely on negative emissions thus require large areas of productive land, with estimates in the literature ranging from 100 million to almost 3,000 million hectares (Mha). The upper end of this range is equivalent to twice the world's currently cultivated land.

Large-scale use of land for negative emissions options could reduce the amount of land available for food production. Moreover, it could disproportionately affect indigenous peoples and others whose customary or traditional land tenure is often not legally recognized. Large-scale land transfers and displacement exacerbate poverty, food insecurity and conflicts.

In addition to social impacts, land-based mitigation activities can degrade land and compromise ecosystems. Because land-intensive negative emissions activities could conflict with biodiversity objectives, such activities are covered by a moratorium on geoengineering adopted by the Convention on Biodiversity (CBD), which includes “increasing carbon sequestration from the atmosphere on a large scale that may affect biodiversity”.

Risk type 3: Negative emissions are not as effective as expected

Even if negative emission options prove feasible, and can be undertaken at large scale without adverse ecological and social consequences, they could still prove less effective than expected at reducing climate impacts. Land-based carbon stocks are inherently prone to reversal – a risk exacerbated by climate change – and allowing a period of climate overshoot could lead to irreversible climate impacts.

The peak warming is driven by time-integrated radiative forcing, and is a function of maximum cumulative emissions (before negative emissions start), rather than total cumulative emissions (including negative emissions). The higher peak warming causes greater climate impacts and increases the risk of crossing thresholds that lead to irreversible changes. Of particular concern is the potential to pass thresholds relating to sea ice, glaciers, ice sheets and permafrost, which can themselves create a positive feedback that causes additional warming.

Evaluating land-based negative emission options

Around 10% of global emissions are from land use change: deforestation, forest degradation and drained peatland in tropical regions. Although reducing emissions from land use change does not constitute a form of negative emissions, halting land use emissions is a key part of low-carbon pathways, and forest regeneration can only be used to store carbon if first we stop and reverse forest loss. Global initiatives to reduce and halt forest loss have scaled up significantly in the past decade, including a Sustainable Development Goal target to halt global deforestation by 2020.

These efforts could bring significant benefits aside from carbon, including biodiversity protection, watershed protection and rural livelihoods. Research has shown that one of the key ways to protect forests is to secure communities' land tenure rights.

Forest ecosystem restoration

Along with protecting healthy forests, it is important to enable or accelerate the recovery of degraded forests. The mitigation potential is significant, because degraded forests store far less carbon in the trees and the soil than undisturbed forest ecosystems. Forests can recover unaided if protected from further disturbance, but natural recovery of degraded forests is less feasible where the ecosystem has lost its biodiversity and soils are depleted, highlighting the immense difficulty of reversing the loss of biodiversity-rich native forests.

By one high-profile estimate, forest ecosystem restoration could in principle remove as much as 1–3 Gt C/year from the atmosphere (in addition to the natural land-carbon sink).¹ However, it is important to recognize the social limits to forest regeneration. Restricting swidden agriculture, for instance, and/or sustainable harvest of secondary forests, could significantly affect livelihoods.

Given these constraints, we consider the lower end of the range cited above a more realistic estimate of the potential for future carbon sequestration from ecosystem restoration, to allow for existing land uses. Achieving this rate of carbon sequestration would still be extremely challenging, requiring forests to switch from a net carbon source of 1 Gt C/year to a net sink of at least the same magnitude. This requires both reversing forest loss and facilitating the effective long-term, stable regeneration of degraded forests.

Reforestation

Reforestation refers to human interventions to re-establish forest on lands that were forest at some time in the past.² This differs from ecosystem restoration in that the land's capacity for natural regeneration has been lost or severely impaired. Replanting these areas results in forests with lower biodiversity and lower carbon storage capacity than natural forests, so the total mitigation potential is lower than from restoring degraded forests.

¹ Houghton, R.A. (2013). The emissions of carbon from deforestation and degradation in the tropics: past trends and future potential. *Carbon Management*, 4(5). 539–46. DOI:10.4155/cmt.13.41.

² Reforestation here refers to reforesting historically deforested lands, while afforestation refers to establishing forests on landscapes that do not naturally support forests. The CBD moratorium on geoengineering can be interpreted as applying to afforestation with non-native species.

Table 1: Options for achieving 370–480 Gt CO₂ negative emissions

Negative emission category		Cumulative sequestration (21st century)
Ecosystem restoration	Extensive ecosystem restoration, sufficient to enhance the natural sinks at an average rate of 1 to 1.5 Gt C/year for 60 years until saturation, yields 60 to 90 Gt C of cumulative removals.	≈220–330 Gt CO ₂
Reforestation	Assuming optimistic levels of reforestation consistent with established global targets to reforest an additional 350 Mha by 2030, yields an average negative emission rate of 0.7 Gt C/year (which accords well with the middle of the IPCC range). Over 60 years until saturation, yields approximately 40 Gt C of cumulative removals.	≈150 Gt CO ₂
Bioenergy with CCS	Negative emissions from BECCS are excluded, on the basis that the technology is not yet proven, and that bioenergy supply at the scale expected would require decreased consumption in the agricultural sector to free up land and other resource inputs for primary bioenergy production, and/or a technological breakthrough in bioenergy production not reliant on land.	0 Gt CO ₂
Total	Note this total is based on global estimates which carry high degrees of uncertainty.	≈370–480 Gt CO ₂

It has been estimated that reforesting an area of 500 Mha would capture about 1 Gt C/year, declining after 60 years due to sink saturation.³ This is toward the upper end of the roughly 0.5–1.15 Gt C/year range given in the last two Intergovernmental Panel on Climate Change (IPCC) assessments.

The ecological and social implications of reforestation on such a large scale depends on many factors. Fast-growing commercial plantation species require significant inputs of water, nitrogen and phosphorus. Reforestation of mixed species and in carefully chosen sites, on the other hand, could increase biodiversity and restore waterways. This points to scale, spatial location and species type as key considerations for reforestation.

A more cautious estimate of the land available in the future for reforestation is provided by the targets of the Bonn Challenge and the New York Declaration on Forests: to reforest 350 Mha by 2030. These global targets for reforestation are not solely focused on maximizing carbon sequestration, but also on realizing broader social and ecological benefits – for example, relying on community-managed forests to reduce the risk of adverse impacts.

Bioenergy with CCS (BECCS)

While a key constraint on BECCS is the uncertainty of CCS technologies, we consider the more limiting factor to be the availability of bioenergy supply. As noted earlier, a key determinant of bioenergy supply potential is the maximum net primary production (NPP) of plant growth. Taking into account existing human harvest of NPP, an upper biophysical limit in primary bioenergy supply has been estimated at approximately 190 EJ/year, with another 60 EJ/year from waste and residues bringing the total to ≈250 EJ/year.⁴

In practice, reaching 250 EJ/year in bioenergy output would require a doubling of current human biomass harvest (all crops, feedstock and other materials) which suggests serious social, economic and ecological constraints that are often neglected in estimates of bioenergy potential. Notably, even though the IPCC finds there to be decreasing agreement on the sustainable technical potential of bioenergy beyond 100 EJ/year, many models assume bioenergy production of 250–500 EJ/year.

Key uncertainties in total bioenergy potential lie in the availability of land for dedicated energy crops; the potential for yield increase; and trade-offs with other land uses, such as food production and biodiversity. Bioenergy has been identified by the IPCC as an emergent global risk to food security and ecosystems due to indirect land use change.

In light of these considerations, we find that society cannot count on dedicating large amounts of land for future bioenergy feedstock production. That leaves only wastes and residues, which are only available at limited scales at which CCS may not be cost-effective. It is irresponsibly risky to assume the future availability of large-scale BECCS until the feasibility of the required technologies is proven and robust institutions and practices are developed to scale up bioenergy feedstock production without unacceptable ecological and social costs.

Implications for limiting warming to 1.5°C or 2°C

Our analysis suggests that the potential for negative emissions is limited, at least from land-based measures using existing technologies. Yet a recent meta-analysis of some 200 modelled scenarios found negative emissions requirements of up to 1,000 Gt CO₂ for scenarios that limit warming to 1.5°C, and up to 900 Gt CO₂ for scenarios that limit warming to 2°C.⁵

However, a large number of the modelled 1.5°C and 2°C pathways also require considerably less negative emissions. Specifically, the meta-analysis found that a total of 480 Gt CO₂ would be sufficient to meet the negative emission needs of more than one-third of the 1.5°C scenarios and more than half of the 2°C scenarios reviewed. The authors also noted that the literature includes 2°C scenarios with little or no contribution of negative emissions. All these pathways still require a prompt, rapid and dramatic transformation of the economy to shift away from fossil fuels and minimize land use-related emissions.

Table 1 presents our estimate of land-based carbon sequestration potential, using only options that have a reasonable probability of being technically and socially feasible. We find a range of 370–480 Gt CO₂ cumulative carbon sequestration,

³ Houghton (2013), op. cit.

⁴ Haberl, H., Erb, K.-H., Krausmann, F., Running, S., Searchinger, T. D. and Kolby Smith, W. (2013). Bioenergy: how much can we expect for 2050? *Environmental Research Letters*, 8(3). 31004. DOI:10.1088/1748-9326/8/3/031004.

⁵ Rogelj, J., Luderer, G., Pietzcker, R. C., Kriegler, E., Schaeffer, M., Krey, V. and Riahi, K. (2015). Energy system transformations for limiting end-of-century warming to below 1.5°C. *Nature Climate Change*, 5(6). 519–27. DOI:10.1038/nclimate2572. The scenarios considered are for a 50% likelihood of limiting warming to 1.5°C by 2100, after overshooting in the interim, and for a 66% likelihood of limiting warming to 2°C.

Policy recommendations

- Greatly increase near-term mitigation ambitions. If governments recognize the urgency of climate action, they cannot be content with the pledges made under the Paris Agreement. Countries need to step up their efforts, including both national-level policy action and international cooperation to provide financial and technological resources to developing countries.
- Implement good land use practices, which includes securing land rights. Good land management, especially ecosystem restoration and ecologically sound reforestation, would provide multiple social and ecological benefits – and also contribute to achieving global climate change mitigation goals.
- Establish policies and institutions to safeguard and support livelihoods and food security. Deploying land-intensive negative emissions technologies on any scale (including well below the estimates in many models), would require effective global governance networks to manage trade-offs and the development of integrated land use policies. A good start is to establish a “food first” approach to land use to deter the (further) conversion of land to non-food purposes.
- Don't count on unproven options to meet climate goals. Prudence demands that climate change mitigation strategies rely on measures that can be deployed with confidence on a large scale, and that we know we can count on. To the extent that negative emissions options become feasible at significant scales, we can make use of them – after carefully choosing how and where to deploy them to avoid negative social or ecological impacts. But first, we need to do everything in our power to reduce emissions, promptly and aggressively, and to build low-carbon, more sustainable economies.

which the above meta-analysis suggests may be sufficient for limiting warming to 1.5°C. It is also important to stress that, although the measures in Table 1 may not be greatly susceptible to risks of Type 1 (technological infeasibility), they still pose risks of Type 2 (adverse social and ecological impacts) and potentially substantial risks of Type 3 (ineffectiveness).

These measures would also still be extremely challenging to achieve, and would impose a demand for land that could jeopardize other critical land uses, such as food production, habitat, and biodiversity. Thus, they present serious risks, which increase with the scale of deployment. It is conceivable – though by no means guaranteed – that measures such as ecosystem restoration and reforestation could be implemented in a manner that achieves the required amount of negative emissions without jeopardizing other critical land uses.

Implications for climate policy

It is a bad strategy to rely on large-scale future negative emissions without reasonable confidence that there will be ways to achieve them through options that are technically feasible, ecologically and socially acceptable at the required scale, and effective. Such a strategy could leave us – and future generations – stranded with an insufficiently transformed energy economy and a carbon debt that cannot be repaid.

If the expected negative emissions cannot ultimately be achieved, the decades in which society had allowed itself a slower, softer transition would turn out to be a dangerous delay of much-needed rapid emission reductions. Saddled with a fossil fuel-dependent energy infrastructure, society would face a much more abrupt and disruptive transition than the one it had sought to avoid. Having exceeded its available carbon budget, and unable to compensate with negative emissions, it could also face more severe climate change impacts than it had prepared for.

This is particularly important for policy-makers trying to determine what near- and medium-term climate actions are needed to keep warming below 1.5°C or 2°C. Any pathway that relies heavily on negative emissions will require far less aggressive mitigation efforts in the next few decades. If those negative emissions fail to materialize, or they cannot undo the damage already done, a strategy aimed at keeping warming below 1.5°C or 2°C might easily result in 3°C or more warming.

Policy-makers would thus be well advised to be sceptical of any “1.5°C” or “2°C” pathway labelled as “likely” to keep warming below 1.5°C or 2°C if it relies on negative emission options that themselves do not have a “likely” chance of proving feasible and providing reliably permanent and effective reductions at the needed scale. At this point, the evidence simply does not support reliance on these options to provide permanent, effective emission reductions on the large scale often taken for granted.

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