EDITORIAL COMMENTARY

Considering sustainability thresholds for BECCS in IPCC and biodiversity assessments

A recent IPCC report emphasized bioenergy with carbon capture storage (BECCS) as a key technology for staying below 1.5°C or 2°C global warming, yet another IPCC report highlights high risks of BECCS in the land domain. Here, we contrast insights from these reports with other recent literature and demonstrate that BECCS bears additional risks for biodiversity, livelihoods, and intertemporal carbon balances. We point out that the majority of scenarios that meet the goals of the Paris agreements exceed sustainability and precautionary thresholds in land and BECCS potentials. Risks may be best avoided by demand-side-driven rapid decarbonization and less land-intensive carbon dioxide removal technologies.

Bioenergy with carbon capture and storage features prominently in many climate stabilization scenarios, and is envisaged as a feature of energy sector and land-based mitigation (Roe et al., 2019; Rogelj et al., 2018). The IPCC Special Report “Global Warming of 1.5°C” (SR1.5) presents BECCS in three of four illustrative pathways as essential for realizing mitigation targets (Table 1, IPCC, 2018). Compensating for past and present GHG emissions, BECCS is modeled to deliver up to about 20 Gt CO2 sequestration per year, requiring several million square km of land (Table 1, IPCC, 2018). Surprisingly, even a scenario framed as “sustainable” (P2 in Table 1) relies strongly on BECCS and associated land demand of nearly 1 Mkm2 (1 Mkm2 = 1 million square kilometers = 1012 m² = 100 Mha). In scenarios where societies reduce GHG emissions rapidly, and reduce demand for energy and GHG emission-intensive goods (P1 in Table 1), BECCS is not required (Grubler et al., 2018).

A subsequent IPCC Special Report “Climate Change and Land” (SRCCL) investigated the relationship between climate change (including climate change mitigation) and land (IPCC, 2019). Discussing bioenergy, the report concludes:

… there are limits to the deployment of land-based mitigation measures such as bioenergy crops or afforestation. Widespread use at the scale of several millions of km² globally could increase risks for desertification, land degradation, food security and sustainable development.

The SRCCL also specifies that in scenarios with low population growth and effective land-use management (including low-GHG emission food systems, requiring less land for meat production), bioenergy becomes moderately risky if deployed at a scale between 1 and 4 Mkm², whereas in scenarios with high population growth, comparatively lower income and presumably less effective global land management, the threshold is reduced to 0.1–1 Mkm² of land. Risks assessed in the SRCCL are impacts on five main land challenges: mitigation, adaptation, desertification and land degradation, and food security; biodiversity is not explicitly treated in the report (Table 1). Among the 32 land-based response options to address the five main land challenges, bioenergy had the highest evaluated risk, particularly for food security (Table 1, IPCC, 2019).

Both IPCC reports demonstrate that achieving stringent GHG reductions to limit global warming at 1.5°C can take a variety of paths. On the extreme ends of the pathway spectrum, societies either reduce GHG emissions drastically until 2050, including drawing on demand-side options, or conversely, push mitigation to later in the century and depend on a massive scale of BECCS—an option that is considered as risky from a perspective of global land use. Since the publication of the IPCC reports, BECCS continues to be modeled as the dominant cost-effective long-term mitigation strategy, with more than 10 Gt CO2 realized in 2100 across most integrated assessment models (IAMs; Muratori et al., 2020).

Here, we revisit the literature on BECCS based on climate change mitigation, and evaluate risks beyond those considered in the SRCCL to include biodiversity, livelihoods, and tipping points related to carbon accounting. We raise three overarching concerns. First, we consider it crucial to discuss the assumptions on the scale of deployment, which are critical to contextualize the magnitude of possible trade-offs, particularly for biodiversity. Second, we raise issues of land distribution, availability, and access that are key for the...
sustainable implementation of BECCS. Third, we discuss the time dimension of the deployment assumed in the study to clarify the underlying principles of land use-based emissions, critical to understanding the overall contribution to climate change mitigation efforts to harness BECCS potential at the scale envisaged in the highly visible IPCC scenarios.

1 | SHOULD FORESTS BE CUT DOWN TO PROMOTE BECCS?

Mitigation scenarios for 2C and 1.5C pathways from IAMs rely on 2–15 Mkm$^2$ (median value 6 Mkm$^2$) of land for energy crops in 2100 and deploy 0.4–13.5 Gt CO$_2$/year in 2050 (median value 4.5 Gt CO$_2$/year) and 3–29 Gt CO$_2$/year in 2100 (median value 14 Gt CO$_2$/year, Figure 1). Bioenergy and BECCS also use tree biomass in some IAMs, which may not be reported in the land area planted with energy crops, but rather in increased forest area from A/R. Once ecological concerns are put on equal footing as economic ones (Creutzig, 2014), these values can be seen as very high and not sustainable.

Arguably, a set of extreme scenarios leads to the impression that the scenario values could nonetheless be seen as reasonable. For example, in a specific instance of modeled future BECCS deployment on land that is not used for food production, a 40 Gt CO$_2$/year BECCS potential draws on 44.3 million km$^2$ of land in 2100 (Hanssen et al., 2020). This is more than the entire land mass of Russia, United States, China, and the EU combined. It is larger than the current best-guess estimate on the global extent of all forests, primary and secondary, including forest plantations (40 Mkm$^2$; IPCC, 2019). While the exact pattern of bioenergy plantations is not disclosed, the bioenergy yields displayed in Figure S1 in that study suggest that the assumed BECCS implementation will entail the loss of (almost) all tropical and subtropical forest and savannas. Occupying this amount of land may produce a potential of ~220 EJ/year of bioenergy (at low yields of 0.3 kg dry matter biomass per m$^2$/year). The authors mention that more limited deployment is advisable, considering the land requirements. The effect of extreme and unrealistic scenarios is that other scenarios, like those presented from the scenario database, that may use “only” half of land or require half as much BECCS may be seen as plausible (in psychology, this is labeled anchoring). Such an interpretation is, however, misleading.

Current biomass for bioenergy is in many cases related to acidification, eutrophication, water footprint, and biodiversity loss (Jeswani et al., 2020). Deforestation of greater than the current levels (average of 0.26 Mkm$^2$ between 2014 and 2019; NYDF Assessment Partners, 2019) to expand plantations and/or energy crops for bioenergy would be incompatible with sustainability targets, including climate protection (the biophysical effect and forgone sequestration of deforesting tropical forests would largely offset any potential gains). Global assessments of land use show that competition for land, or even conflicts over land, is already encroaching on natural resources (Creutzig, d’Amour, et al., 2019), and that projected future land requirements for urbanization, food production, bioenergy, and biodiversity are incompatible with each other (Creutzig, 2017). The anthropogenic sixth mass extinction is accelerating, driven most prominently by human expansion of the built environment and agriculture, direct exploitation and climate change (IPBES, 2019). While climate change mitigation can temper one of the drivers of

| TABLE 1 | Bioenergy with carbon capture storage (BECCS) is a main technology for climate change mitigation and in many scenarios deployed at scales compromising sustainability of land use. Four illustrative pathways of the IPCC’s special report on global warming of 1.5°C based on Figure SPM.3b of the IPCC SR1.5 report (IPCC, 2018). Three out of four illustrative pathways chosen rely on BECCS. Even a pathway with focus on sustainability (P2) requires about 3 Gt CO$_2$/year of BECCS from 2050 onward. Last row: Impact evaluation of large-scale bioenergy deployment imputed from Figure SPM.3b of the IPCC SRCCL report (IPCC, 2019). Thirty-one other response options to mitigation, adaptation and combating land degradation are evaluated more positively compared to bioenergy and BECCS |
| --- | --- | --- | --- |
| P1: Low energy demand, rising living standards, no CCS nor BECCS | P2: Sustainability and economic convergence but with some BECCS | P3: Trends following historical patterns; focus on energy supply technologies | P4: Resource-and energy-intensive development based on fossil fuels; lots of BECCS |
| Cumulative CCS until 2100 (Gt CO$_2$) | 0 | 348 | 687 | 1218 |
| … of which BECCS (Gt CO$_2$) | 0 | 151 | 414 | 1191 |
| Land area of bioenergy crop in 2050 (million km$^2$) | 0.2 | 0.9 | 2.8 | 7.2 |
| Impact evaluation: Negative impact on food security, adaptation (and less certain: land degradation and desertification) on a scale from 0 to 5 | 0 | 1 | 3 | 5 |
biodiversity loss, land cover and land use change are even greater threats to biodiversity (Newbold et al., 2016), having lifted extinction rates far above natural levels (IPBES, 2019). The total stock of mammals, birds, amphibians, reptiles, and fish, for instance, declined by 68% from 1970 to 2016, driven inter alia by expansion of intensive agriculture (WWF, 2020). As a result and while acknowledging diverse land use and biodiversity impacts from different bioenergy feedstock (Ale et al., 2019), a bioenergy-relieant mitigation strategy above certain thresholds, through the loss of natural habitats of probably unprecedented dimensions, would be much more detrimental to global biodiversity than in a counterfactual higher climate change scenario (Hof et al., 2018). Thresholds may include both sequestration and land use. A systematic review suggests that a potential of 0.5–2.0 Gt CO₂/year of BECCS in 2050 may be sustainable (Fuss et al., 2018; Figure 1b). Of 192 scenarios from the IAMC database exploring trajectories respecting the Paris Agreement (IIASA, 2020), 172 (91%) are above the lower threshold suggested (0.5 Gt CO₂/year), and 33% are above the higher threshold (5.0 Gt CO₂/year).

Sustainability of the energy dimension has also been considered. One study suggests that realistic bioenergy potentials include about 25 EJ/year derived from residues and manure, and between ~10 and ~50 EJ/year from energy crops in 2050, with the range primarily depending on land demand of the food system (Kalt et al., 2020). Higher bioenergy potentials would be possible only if global livestock systems are restructured, which would raise difficult implementation issues. Reasonably low GHG emissions per unit of bioenergy can only be ascertained if limits set by the need to conserve C-rich ecosystems are respected (Kalt et al., 2020). Unless there are large future efficiency gains in agriculture and/or available areas are identified that will have no impact on biodiversity and food security, we assume that land used for bioenergy should not exceed the
current amount of land used for bioenergy, about 0.5 Mkm$^2$ (“precautionary threshold value”), to avoid adding pressure on land use (Figure 1a). Of 132 scenarios of the IAMC database that present land use, 126 (97%) are above this precautionary threshold.

Large-scale BECCS and its associated land use would likely steer the earth system closer to or beyond planetary boundaries associated with freshwater use, biosphere integrity, and biochemical flows (Heck et al., 2018). Preventing further losses to terrestrial biodiversity instead requires unprecedented land conservation efforts (Leclère et al., 2020).

2 | MYTHS OF “EMPTY LAND”

The world’s forests and savannahs are not “empty lands” available for conversion to cultivation—a myth debunked long ago (Young, 1999). They are home to people whose food security and livelihoods critically depend on these ecosystems. Large-scale acquisitions or conversion of such lands have been historically entangled with various forms of colonization and land enclosures, with the effect of dispossessing rural and forest communities and pushing them into low-wage job dependency, migration, or the deadly combination of landlessness and joblessness (Young, 1999). Forest people in many tropical countries, including Indigenous and ethnic minority groups, have long been marginalized and excluded by state forestry regimes (Li, 2010). Claims about the “environmental” value of bioenergy are one of several narratives already being used to justify encroaching on customary tenure and consolidating land control (Fairhead et al., 2012). In short, the scale of land use change implicit in large-scale BECCS deployment would cause enormous social dislocation. Even much smaller bioenergy cropland expansion plans will still need to address and avoid risks related to land tenure, livelihoods, and Indigenous rights.

3 | EMIT FIRST, SEQUESTER LATER?

A fundamental issue of BECCS relates to the time dimension of deployment. A crucial assumption of various IAMs included in the SR1.5 and SRCCL is that large emissions arising in the near future are to be compensated in the far future by multi-decadal use of land for BECCS or other CDR technology (Obersteiner et al., 2018). In the case of BECCS, the assumption of producing a certain amount of land-use change-related emissions first, and then relying on uncertain emission reductions several decades later entails a significant risk. It assumes a long-term commitment on land use, even as climate, water, and political circumstances are changing, and does not consider economic incentives to rededicate land for other purposes. High upfront emissions and possible overshoot in emissions also risk exceeding environmental thresholds for coral reefs and other ecosystems, like the Amazon and the Arctic, and risk triggering runaway GHG emissions (Witze, 2020). It may be irrelevant how much CO$_2$ is sequestered in the second half of the 21st century by BECCS if runaway feedback loops releasing large amounts of CO$_2$ are triggered (Lenton et al., 2019).

The risk of tipping points in the climate system makes early and deep emission reductions and removals necessary. The archetypal BECCS deployment in most models follows the rapid-out/slow-in mechanism of bioenergy based on the replacement of C-rich ecosystems (Körner, 2003), or a scenario of high initial carbon losses and late deployment of BECCS, while aiming at a rapid decarbonization of the industrial system. The timescales underlying the BECCS potentials across the IPCC models render BECCS a highly risky technology and mismatch with the urgency of fast GHG reduction underlying the Paris Agreement (Norton et al., 2019).

4 | IS BECCS COST-EFFECTIVE?

Also the understanding of BECCS as a cost-effective solution is misplaced. In 2012, wind and solar energy were already realized as more cost-effective and land-sparing energy solutions (Pogson et al., 2013). Since then, solar power and battery storage costs have decreased substantially (Green, 2019; Nykvist & Nilsson, 2015), a dynamic not yet reflected in most currently published IAM scenarios (Creutzig et al., 2017). This renders the energy generation aspect of BECCS less important than previously considered (Creutzig, Breyer, et al., 2019), and instead emphasizes the affordable opportunity of rapid decarbonization, thus reducing reliance on carbon dioxide removal technologies.

5 | A DIMINISHED ROLE FOR BECCS IN FUTURE SCenarios

In conclusion, realistic potentials that also account for biodiversity, land tenure, livelihoods, and the risk of land carbon loss are perhaps one-fifth of high-end requirements reported in the illustrative pathways. The large-scale deployment of BECCS later in the century to offset emissions from earlier in the century poses potentially higher levels of risk for the biosphere and anthroposphere than captured in the SRCL risk assessment. BECCS implementation at the mid and higher levels of model scenarios (i.e., those greater than 0.5–5 Gt CO$_2$/year) is problematic for accumulating up-front climate carbon debts, and for compromising planetary health in areas besides climate change. Excluding those scenarios from the aggregated IPCC mitigation potential ranges and pathways
or labeling them as undesirable and unrealistic would be helpful for non-modeling experts, particularly policy makers.

Fortunately, a diminished role of BECCS does not translate into doom for climate change mitigation. Two complementary strategies, instead, deserve priority: (1) Pursuing a portfolio of negative emission technologies, including technology intensive but land sparing options such as direct air capture that require at least a factor 100 less land (Creutzig, Breyer, et al., 2019); and (2) reducing energy demand (Grubler, 2012) and shifting diets and reducing food waste (Springmann et al., 2016) by establishing more efficient service provisioning systems consistent with high well-being.

KEYWORDS
BECCS, biodiversity, climate change mitigation, IPCC, livelihood, sustainable

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