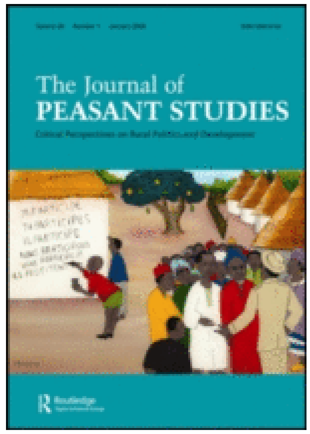

Advocating afforestation, betting on BECCS: Land-based negative emissions technologies (NETs) and agrarian livelihoods in the global South

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Introduction

Ongoing failures to achieve sufficient reductions in greenhouse gas emissions have led to increasingly important discussions of the potential need for negative emissions technologies (NETs) to remove existing CO_2 from the atmosphere (Smith et al. 2015). These carbon dioxide removal (CDR) strategies include direct air capture as well as land-based actions like afforestation or bioenergy with carbon capture and storage (BECCS), and are often grouped together with other 'geoengineering' solutions to the climate crisis (NAS 2015). NETs are an important element within modelled pathways that demonstrate how the world could achieve the Paris agreement target of holding global temperature to well below 2°C (Dooley and Kartha 2018, Rogelj *et al.* 2018).[1] While there is an increasingly large literature discussing NETs, it remains mostly focused on modelling pathways and technical feasibility, with fewer critical discussion of social impacts of deployment, and particularly of the local impacts for rural peoples (Williamson 2016, Sovacool 2021).

The potential environmental constraints of large-scale use of NETs include water scarcity and biodiversity loss, which will also have socio-economic impacts (Dooley and Kartha 2018, Yamagata *et al.* 2018, Dooley *et al.* 2021). A small number of studies have engaged social scientists to identify key concerns, such as public understanding and acceptability as barriers to deployment (Buck 2016), or tradeoffs with sustainable development goals (Smith *et al.* 2019, Honegger *et al.* 2020, McElwee *et al.* 2020). Several recent reviews have highlighted other key social questions, including complexity, uncertainty, ethics, and justice (Gough *et al.* 2018, Forster *et al.* 2020, Waller *et al.* 2020), while stronger critiques have also emerged, including

[1] For example, the IPCC 1.5 report has only one modeled pathway (P1) with no use of BECCS: this pathway requires very low energy demand (LED), rapid phase-out of fossil fuels and/or rapid shifts to sustainable food consumption freeing up land for afforestation (IPCC 2018, p 122). Other modelled pathways all rely on NETs of some kind.

concerns that NETs are being used as a smokescreen to avoid difficult fossil fuel emissions reductions (Cox *et al.* 2018, Carton 2019, Stuart *et al.* 2020).

Yet there contributes to be a strong need for social scientists to engage with discussions regarding the feasibility and desirableness of NETs (Markusson *et al.* 2020). In particular, there has been insufficient attention to land-based NETs as a uniquely *rural* or *agrarian* challenge for the global South. To address this gap, this article aims to 1) assess the range of technical studies on NETs to determine what rural social challenges are currently considered in modelling studies and which excluded; and 2) to examine lessons learned from other agrarian literatures on interventions such as tree planting, biofuels, and reduced emissions from degradation and deforestation (REDD+). Such comparisons are sorely needed, as even those scholars who are critical of the overall techno-optimism in NETs tend to see land-based options as more benign or even beneficial (Stuart *et al.* 2020).[2]

This paper addresses how NETs might threaten the concept of 'agrarian climate justice' – that is, a just and equitable response to the impacts of climate change that addresses historical injustices and presents a more progressive vision for the future (Borras Jr. and Franco 2018). As the call for this special forum has noted, the implications of climate change for rural spaces and peoples is profound, from the expansion of techno-fixes and extension of neoliberal capital to the need to understand increasingly reactionary agrarian politics (Borras Jr *et al.* 2021). The problems of deployment of NETs encapsulates many of these challenges, particularly regarding the lack of attention to justice-related issues. For example, there are clear problems of procedural justice (e.g. involvement in decision-making), given the lack of public awareness of the issues

[2] For example, land-based NETs are often presented as providing co-benefits (e.g., forest ecosystem services, increased agricultural productivity, or electricity) with fewer negative trade-offs (Smith et al. 2019). A 2015 National Academy of Sciences report stated that land-based NETs raise few ethical issues as compared to others like ocean fertilization or solar radiation management (NAS 2015).

and technologies involved in many geoengineering approaches (McLaren 2012, Gough and Mander 2019, Spence *et al.* 2021). Distributional justice around who benefits (and who bears the costs) from NET interventions is also key, particularly as some will involve difficult tradeoffs that may result in exacerbation of already uneven access to land (Smith *et al.* 2015).

Examining NETs across axes of agrarian change provides a useful way to pre-assess the possible impacts of different options. However, there remain large gaps in the literature on rural social impacts in particular (Robledo-Abad *et al.* 2017). By explicitly analyzing the implications of different NETs for land, labor, capital, and politics in rural spaces, this paper confirms that existing discourses and plans for NETs continue to follow mostly technocratic and capitalist models. In other words, NETs are seen as technologies rather than practices that involve and impact people (Buck 2018). Such approaches are bolstered by use of modelling that often fails include social factors to improve more realistic understanding of the feasibility of NETs (Schweizer *et al.* 2020). In contrast, agrarian studies scholarship that foregrounds the experiences and expectations of rural peoples can help identify potential risks and roadblocks before NETs are deployed, as well as designing strategies and investments that are more beneficial to rural peoples, including through attention to procedural and distributional forms of justice (Morrow *et al.* 2020, Batres *et al.* 2021, Healey *et al.* 2021).

Methods

Literature searches were conducted in Web of Science for a range of land-based NETs, with a particular focus on results in social science journals. For example, the term BECCS alone received 242 hits, of which the most relevant papers were examined for agrarian or social science questions. Because many of the NET options are future-oriented (e.g., BECCS is not yet fully operational), these literatures often rely on modelling of different scenarios for the scale and scope of NETs to the end of the 21st century. A total of 81 papers on the technical details of NETs and 105 papers on governance and social implications of NETs were reviewed and examined for discussions of justice-related issues (namely benefit distribution or participatory approaches) across key categories of land, labor, capital, and rural politics. In addition, an additional 89 studies of existing land-based carbon emissions projects, particularly afforestation for carbon benefits and REDD+ , were collected in a conventional 'snowball' fashion and examined for challenges to achieving co-benefits and avoiding tradeoffs, which holds lessons for future NETs (Wittman and Caron 2009, Corbera and Brown 2010, Leach and Scoones 2013, Lund *et al.* 2017). Additionally, the pledged Nationally Determined Contributions for all countries that are parties to the Paris Agreement were also searched for reference to use of NETs in current or future plans through use of Google search engine strings on the UN Framework Convention on Climate Change website.

Examining Land-based NETs

NETs aim to remove CO_2 already emitted, providing an opportunity to counterbalance future emissions, particularly 'residual' ones which will be impossible to eliminate entirely through existing mitigation measures. There are a range of possible NETs, including carbon capture and storage from power plants and direct air capture, as well as ocean fertilization. These remain technologically far-off, thus NETs that feature most prominently in current modelling efforts to explore future emissions pathways tend to be land-based, including bioenergy with carbon capture and storage (BECCS) and afforestation/reforestation. Other land-based NETs include enhanced weathering of minerals, carbon storage in soils, and use of biochar (Figure 1).[3]

[3] Biofuels are not considered a NET, as they are primarily a substitute for fossil fuels and thus a mitigation strategy. REDD+ occupies a more ambiguous position as both a mitigation strategy to reduce forest emissions from deforestation (avoided emissions), as well as a possible NET for negative emissions if forest cover expands

<Figure 1. How land-based NETs work>

Afforestation involves the conversion to forest of land that historically has not contained forests, while *reforestation* occurs on land that has previously contained forests: both can contribute to negative emissions given trees' carbon sequestration potential (see Table 1). Where trees are planted is crucial, as afforestation in boreal areas contributes to the albedo effect, effectively prioritizing afforestation in the tropics instead (Fuss *et al.* 2018).[4] Both *soil carbon sequestration* and *biochar* relate to the preservation or amendment of soils. Practices to conserve carbon within soils include low or no till, cover crops, nutrient and water management, and other practices, while biochar is created by the combustion of biological material under pyrolysis which locks up some carbon and which can be added as an amendment to soil (Smith et al. 2019).

While soil carbon sequestration, biochar, and afforestation are all existing options, *BECCS* and *enhanced mineralization* are more speculative. BECCS requires the production of bioenergy feedstocks (generally fast-growing species like miscanthus or switchgrass) which must then be transported to where they will be converted to steam/heat, liquid fuels, or charcoals. These fuel products are then used for energy generation and the emitted CO_2 is captured either pre- or post-combustion and stored (NAS 2019). For enhanced mineralization, certain basaltic rocks can form carbonites by reacting with CO_2 in the air, and mining these rocks, grinding them, and spreading them across land surfaces could increase CO_2 sequestration significantly enough to be a potential NET, although this would require application on large amounts of land

(increased carbon sink). In general, existing natural forest sinks should not be counted as NETs, because they are already calculated in global carbon balance estimates (Nolan *et al.* 2021)

[4] Albedo effects result from planting (darker) trees on (lighter) lands in northern regions, which contributes to increased solar radiation absorption and localized warming, and thus offsets the benefits of tree planting in terms of global temperature (IPCC 2019).

(Williamson 2016, Fuss *et al.* 2018). It is likely that the tropics would be particularly targeted due to the need for warmer climates to enhance the weathering process (Beerling 2017).

<Table 1: Land-based NETs and their potentials>

NETs and IAMs

NETs have been bolstered by their use in Integrated Assessment Models (IAMs), particularly important in IPCC reports, which bring together both biophysical climate system models with socioeconomic parameters (like population or economic output) expressed through Shared Socio-Economic Pathways (SSPs) to model possible climate futures (McElwee 2021). IAMs can be used to understand how a future end point (like limiting temperature increase to less than 2°) will require specific actions over time, and increasingly, the only way IAMs show the world reaching ambitious targets like 1.5° is to include NETs, which are more or less important depending on other assumptions, like world population and affluence. For example, in SSP5, a scenario where economic growth is strong and fossil fuel use remains high, trying to go back to 2° or less would require massive use of NETs by 2100 (Popp et al. 2017).

However, only BECCS and afforestation have been modelled in IAMs used in recent IPCC reports, while the other NETs are not included due to technical challenges; this has led to some concerns that BECCS is being overemphasized simply because it can be modelled (Furhman et al. 2019). IAMs also show very clearly that the required use of land-based NETs to achieve climate targets will come with trade-offs (Dooley *et al.* 2018). Both afforestation and BECCS require land conversion (that is, shifting from food production or other uses to growing trees and bioenergy feedstocks), and in different scenarios, this expansion of afforestation and BECCS happens at the expense of forest, agricultural, and grazing lands (Popp et al. 2017). However, the social impacts of land-based NETs can only be assessed in either general terms or in hypotheticals (Smith *et al.* 2019). IAMs, for example, can only include some development goals, like poverty rates, food security, economic growth, or water use in very general terms. Other potential impacts from land use change like gender impacts, rising inequality, displacement, land degradation, or biodiversity loss are not included in most IAMs, and thus alternative ways to understand these outcomes are needed.

Examining NETs through an Agrarian Lens

NETs are usually discussed at the global landscape level, with little attention to the specific places in which they will be used (Buck 2018), which makes detailed examinations difficult. Further, many NETs remain mostly speculative, with few demonstration sites or models. Thus, it is useful to compare what we do not know about NETs with what do we know about agrarian impacts of existing land-based climate mitigation measures (including REDD+, carbon forestry, and biofuels).[5] In the sections below, key agrarian issues of land, labor, capital, and rural politics are examined, both from the perspective of NETs technical literature and models for what is modelled and where gaps exist, and from the known outcomes of other carbon and climate focused projects that have happened in the rural South in recent decades.

Land and NETs

Where and how NETs are likely to induce land use change, and the implications of issues such as land tenure, dispossession, or consolidation, is one of the most important impacts of NETs. Land-based NETs can be divided into two major types: those that will induce land competition, because they must be the primary land use where they are deployed (BECCS and afforestation) and those NETs that do not introduce competition and which can be deployed alongside agriculture or other land uses (such as soil carbon, enhanced weathering, or biochar).

[5] For example, existing literature has examined community acceptance or opposition of existing energy and climate projects as a proxy for possible reactions to NETs (Buck 2016, 2018).

For land-competing NETs, key issues concern the scale of their potential use and what other land-based activities will be displaced as a result, with knock-on effects for food prices or biodiversity loss (NAS 2019). For example, BECCS used at small scales would not require land use change if it was fueled solely by residues and wastes from existing agriculture and industrial processes (Fajardy *et al.* 2018). However, more ambitious emissions reductions would require significant land use change. For example, if BECCS was deployed to remove between 3-12 $GtCO_2$ per year, this would likely require between 380 and 700 Mha of land by 2100 (that is, up to 10% of existing total world land use) (Smith *et al.* 2015).[6] The potential for declines in food production as farmers switch lands to produce trees or feedstocks is clear in most IAMs, some of which suggests that up to 1 billion people could be impacted by large-scale deployment (Fuss *et al.* 2018).

Where would land use conversion for NETs likely take place? Most IAMs rely on indicators of land suitability and cost to predict where BECCS or afforestation would be most likely to occur (Riahi *et al.* 2017, Cronin *et al.* 2020), indicating that BECCS is most feasible in areas of 'high biomass yields and relatively low carbon stocks (that is, abandoned lands and typically warmer temperate and subtropical areas)' (Hanssen *et al.* 2020): in other words, predominantly in the global South. BECCS is also more likely to be centered in places with access to ports and export markets for feedstocks. NETs like afforestation are often assumed to be produced on degraded and marginal lands not suitable for agriculture, thereby avoiding competition with food production (Bastin *et al.* 2019): Africa and Latin America are projected to experience the most pressure for afforestation, with one model estimating a need for 630 and 600 Mha of land respectively (Kreidenweis *et al.* 2016). Outside of BECCS and afforestation, the

[6] As of 2017, total world land use for agriculture and forestry was 7,130 Mha (2,429 Mha for forests, 1,426 Mha for agriculture, and 3,275Mha of grasslands (for livestock) (NAS 2019).

other NETs that do not compete for land are somewhat less constrained in where they can be deployed. Studies of land suitability have noted that poor carbon- or water-holding soils tend to be in tropical countries, particularly in Africa, where positive yield effects of inputs like biochar tend to be greater (Robb *et al.* 2020).

However, there remain unanswered questions regarding the use of land for NETs in existing models, for which critical agrarian literatures provide useful comparisons, particularly around 'marginal' lands definitions, the potential impact of land grabbing, and the role of colonial histories and global elites in shaping land use. For example, there is no clear definition of what marginal lands means for NETs, with varying definitions used in different models and contexts. Some models assume land is essentially 'abandoned' simply because it is not being used for high productivity crops (Strengers *et al.* 2008). There are wide estimates of potential availability of these so-called marginal lands: one study proposed 1,300 Mha (including lands where one-third of the world's population is currently farming) as marginal, but recognized that 'only a fraction would be available for afforestation/reforestation and BECCS' due to existing land uses (NAS 2019, p. 118). Critical work on existing biofuels and forest carbon expansion has shown that classifications of marginal lands are often subjective, based on narrative rather than evidence-driven assessments (Unruh 2008, Hajdu and Fischer 2016), and what is defined as marginal land in many national contexts is a political calculation often deployed to expropriate existing land users (Baka 2014, Scheidel and Work 2018). Most IAMs also assume that market prices are the most important factor that would drive farmers to stop food production and use their land for investment in trees or feedstocks. Yet the evidence for crop-switching reveals a more complicated picture than simple economic calculations (Li 2014, Borras Jr. *et al.* 2015). Further, models also usually assume that the lowest productivity farmlands would be abandoned first, but these are often the only places where the poor, women, or marginalized are able to farm (McElwee 2009, Quisumbing and Pandolfelli 2010).

However, despite these concerns, literature searches for BECCS and 'land tenure' as a topic turned up zero studies, as did a search for biochar and 'land tenure.' This is likely because IAMs currently take existing land use as evidence of secure tenure (Cronin *et al.* 2020), and have no indicators (other than price) to inform risks of dispossession. Given the numerous ongoing land tenure conflicts, including a marked rise in land grabs because of biofuel policies in particular (Baka 2014, Hufe and Heuermann 2017), there are strong concerns about potential land grabs being driven by NETs (Leach *et al.* 2012).[7] Experience from these existing land grabs show considerable risks, including food insecurity and poverty increases, particularly from large-scale land acquisitions (Schoneveld *et al.* 2011, Yengoh and Armah 2015, Müller *et al.* 2021). Much of the land investment has been speculative but has nonetheless had significant effects on the ground (Buck 2016, Franco and Borras 2019, Hansson *et al.* 2019); similar results might be expected with some NETs (Richards and Lyons 2016).

In cases of recent land grabs, dispossession has been more common where farmers had insecure land tenure (e.g., farming on state lands) (Bleyer *et al.* 2015, Fisher, Cavanagh, *et al.* 2018), but even clear property rights do not confer security or the ability to shape land deals (Vermeulen and Cotula 2010, Franco and Borras 2021). For example, evidence suggests that even where farmers have not themselves lost land but fear risks of expropriation, they are less likely to invest in on-farm management (Aha and Ayitey 2017). There are also significant cases of local dispossession as driven by smallholders themselves (Osborne 2011, Chen 2013,

[7] Databases of current and proposed land deals indicate that 3.6 million hectares have been acquired for biofuels, mostly in Africa and Latin America (with no landgrabs in Europe or North America), while large-scale land deals for all types of forestry have affected 31.7 million ha, with many in Eastern Europe/Russia (LandPortal data)

Cavanagh and Benjaminsen 2014, Bleyer *et al.* 2015, Olwig *et al.* 2015, Scheidel and Work 2018). Overall, however, the literature suggests that concentrated ownership of tree plantations has been more associated with dispossession (Kröger 2014, Malkamäki *et al.* 2018) (an outcome likely to be relevant for BECCS), while smallholder models have been more broadly positive in terms of food security and biodiversity (Jindal *et al.* 2008, Eijck *et al.* 2014) (more likely for afforestation NETs). Smallholder models have been most successful when local concepts of distributive justice have been recognized (Fisher, Cavanagh, *et al.* 2018), although there have been problems with benefit sharing due to lack of clarity in carbon rights and continencies of contracts (Unruh 2008, Corbera *et al.* 2011, Tienhaara 2012). Further, farmers with smaller landholdings who have engaged in forest carbon projects have often experienced more negative impacts on food security, indicating that the distributions of costs and benefits is often uneven (Aggarwal and Brockington 2020).

Finally, agrarian studies scholars have demonstrated how important historical perspectives on land use change are, as path dependencies from colonial control of land continue to influence current-day trajectories (Chomba *et al.* 2016, Davis and Robbins 2018). For example, legacies of racialized dispossession have shaped political subjects and forest legibility in REDD+ projects in Guyana and Suriname (Collins 2019), while elsewhere land tenure histories have resulted in unequal benefit distribution systems from REDD+ investments (Kashwan 2015). Further, there is an important role for global elites in shaping land projects, which has privileged small numbers of actors over rural communities whose livelihoods are often discounted (Asiyanbi 2016, Ece *et al.* 2017, Hook 2020). Simplistic narratives of crises and degradation that ignore corporate or capitalist drivers are often used to cast blame on local practices for their (perceived negative) climate implications as well as constrain options to those proposed by global financiers (Franco and Borras 2019, Hjort 2020).

Capital and NETs

How financial arrangements for land-based NETs will operate remains an open question. There is likely to be a significant role for private capital, as some corporations are already pledging not just carbon neutrality in their operations but scaling up their investments in NETs specifically.[8] Key economic issues in the literature on NETs primarily focuses on what the total potential costs for each technology are (Fajardy and Dowell 2018, Fuss *et al.* 2018) and how that money might be raised and through what sources. The amount of funding available to NETs will also depend in part on the costs of other emissions reduction options (such as renewables).

The most prominent mechanism within IAMs for incentivizing investments is a carbon tax; models then predict how high a carbon tax would need to be to spur various NET investment. Estimates range from as low as \$6 ton CO_2 for afforestation, while BECCS is likely to only be feasible at \$100-250 per ton of CO_2 (Strengers *et al.* 2008, Humpenöder *et al.* 2014). Carbon prices higher than \$55 a ton could stimulate biochar use (Robb *et al.* 2020), but whether or not farmers benefit from such prices depends on how carbon markets are structured (e.g., if biochar producers rather than individual farmers benefit from incentives). It is currently unclear what form of pricing would be needed to encourage enhanced weathering, given large upfront costs of mining (Edwards *et al.* 2017). Of NETs considered here, only soil carbon sequestration shows positive synergies between carbon prices and food security in models (Frank *et al.* 2017). Achieving 100 $GtCO_2$ of negative emissions from land-based solutions, given a range of prices

[8] See https://stripe.com/blog/first-negative-emissions-purchases

of 10–100 USD per tCO_2, would thus require a total funding flow on the order of 1 trillion USD (Nolan *et al.* 2021).

Global accounting rules on carbon credits (such as those that will be facilitated by Article 6 of the Paris Agreement) will be crucial in understanding how markets for NETs will work (Zakkour *et al.* 2014, Coffman and Lockley 2017, Lockley and Coffman 2018). Existing studies of voluntary carbon markets have indicated that numerous questions around measurement, verification, and value have challenged the easy uptake of existing voluntary carbon offsets (Lohmann 2008, Leach and Scoones 2013). Further, IAMs mostly rely on a globally uniform carbon price within their models, which is unrealistic, yet variable regional or national prices cannot be modelled well (Fridahl and Lehtveer 2018). Additionally, unlike modelling of costs that fall over time for other technologies, BECCS will likely increase in cost at higher scales and more distant time periods due to less land being available over time (Honegger and Reiner 2017). Modelling of costs also tends to be limited to initial establishment; for afforestation, IAMs assume no costs of maintenance over time, even though labor around fire prevention, thinning, and other practices are often needed. Further, IAMs usually assume zero risk for most NETs (that is, that no enterprises will fail given a consistent level of carbon price), which is an overly optimistic assumption. For example, existing biofuels contracts show many failures, because such investments do not price risks well (Tienhaara 2012).

Other questions of interest to agrarian studies scholars, such as what types of investors will be involved, how they will be regulated, and what the equity impacts of north-south investment flows will be, have been less examined for NETs. Funding is very likely to be through multinational actors, as biofuel investments made by complex conglomerates have shown (Borras Jr. *et al.* 2011), and is likely to attract start-ups from previously uninvolved actors in land investment (Leach *et al.* 2012). How such actors and their investments are structured is key to understanding their possible impacts (McCarthy 2010). Evidence from the existing wood pellet industry, which provides a glimpse into what BECCS facilities and supply chains might look like, suggests that multiple investors are required, from family-owned forests to wood brokers to pellet mills to the eventual biomass energy facility across trans-Atlantic chains, and the regulatory apparatuses across these different investments are often minimal (Ramos 2022).

How NETs use contracts vs. ownership models for investing in supply of feedstocks (e.g. for BECCS in particular) will also result in different outcomes, as seen in evidence from plantation forestry projects. For example, land ownership models are a likely pathway for land acquisitions that can dispossess small farmers, while supply contracts are associated with wealth accruing to shareholders of companies but not local laborers (Richards and Lyons 2016). International investment contracts for forest carbon have often disadvantaged local communities due to lack of transparency and local involvement (Tienhaara 2012), while biofuels contracts have been plagued by inflexibility and lack of oversight (German *et al.* 2011). For other NETs that are used in on-farm production by smallholders (e.g., soil carbon and biochar) cost effectiveness is likely to be linked to the ability to enhance agricultural production. Biochar for example has presumed lower abatement costs in developing countries because it can increase crop yields while decreasing need for chemical fertilizer amendments or irrigation (Smith et al. 2019). However, farmers do not experience net abatement costs, but rather upfront costs (such as to purchase and deploy biochar), and thus equity issues are still likely to persist: for example, negative debt cycles for poor smallholders have been noted in biofuels production (McCarthy 2010).

Labor and NETs

Many of the NETs will require labor for deployment, but currently there is little attention to this topic other than an assumption of low labor opportunity costs in rural areas of the global South (Eijck *et al.* 2014). For example, most IAMs do not include labor costs explicitly, and assume that with high enough carbon prices (such as $50/ton or more), labor will be available. Whether NETs will generate labor conditions that would either positively or negative impact rural workers is unknown: for example, production of different feedstocks for BECCS might require effort by either smallholders or waged labor (Eijck *et al.* 2014, Schirmer and Bull 2014). In the latter case, there could be potential risks to investors from not applying appropriate oversight to labor needs, such as violations of child labor laws, safety issues, or non-payment of wages (Eijck *et al.* 2014).

The experience of existing biofuel plantations and forest carbon projects provide useful comparisons. Low-wage and unsteady labor has been common in many forest carbon projects (Smith and Scherr 2003, Greenleaf 2019), particularly for mega-plantations. For biofuels, the employment generated has varied depending on the feedstock, with jatropha generating more jobs than corn, largely due to mechanization of the latter (Hunsberger *et al.* 2017). In some cases, biofuels like palm oil have generated less jobs than land uses that were displaced by these plantations (Li 2011): estimates indicate that land acquisitions for biofuels in Africa have resulted in the loss of jobs at the farm level, including as high as four people displaced for every 1 ha of land acquired (Renzaho *et al.* 2017). Similarly low levels of employment have been reported for forest plantations (Gerber 2011). More employment seems to be generated when smallholders work their own land in outgrower schemes and when processing of goods is done locally (Malkamäki *et al.* 2018), but mechanization in later phases of production tends to reduce employment opportunities (Deininger 2011). Biofuels projects have also varied in terms of part-time versus stable long-term employment (Hunsberger *et al.* 2017, Pirard *et al.* 2017).

There are also questions about whether NETs might drive labor migration; some experience from tree planting projects shows migrants may be preferred because of their willingness to work hard jobs for low pay, but this also makes them vulnerable to exploitation (Malkamäki *et al.* 2018). Similarly, examples from the biofuels literature show that many investors make use of skilled outside labor (Richardson 2010) or migrants for low skill work (Li 2011), with some reports even of debt peonage in biofuel plantations or processing in Brazil ((Hunsberger *et al.* 2017). There is also little attention to gender within labor practices that will be required for NETs. Evidence from other previous afforestation projects indicates that women are often involved as labor but not as owners or beneficiaries of the economic impacts of tree planting (McElwee 2009, Gerber 2011). Physically demanding labor may be assumed to require men only, thereby increasing gender gaps and uneven resource access.

Rural Politics and NETs

Understanding how rural populations may support or oppose NETs has not been part of the literature in any depth. There is an acknowledgement that NETs will need a social license to operate (Buck 2016, Fuss *et al.* 2020), and community support or opposition is likely to be a function of existing values, framings of risk, and the way benefits are understood or shared (Pidgeon and Spence 2017, Cox *et al.* 2018). However, most surveys of the acceptability of NETs have been carried out in the global North and have been framed more by concerns about 'tampering with nature' rather than direct livelihood impacts (McLaren *et al.* 2016, Wolske *et al.* 2019). Existing literature on biofuels or carbon tree planting – both less speculative technologies than some NETs – reveals that social licenses do not confer acceptability if other aspects are not considered (Smith and Scherr 2003). One key lesson is that procedural and recognition justice processes have been important considerations in conferring acceptability (Suiseeya & Caplow, 2013). Understandably, many rural communities have declined to participate in afforestation projects that do not account for local conceptions of justice and equity (Hendrickson and Corbera 2015), or where corporate interests outweigh local land users (Gerber 2011). roduction of feedstocks for BECCS that occur in one location but where the energy generated may flow elsewhere are thus likely to be a sensitive issue that could fuel a sense of injustice (Buck 2018).

Different NETs are also likely to unevenly impact households across class, gender, race and ethnicity and other forms of difference (Borras Jr *et al.* 2021), particularly where NETs generate negative impacts via changes in property rights and labor regimes as noted above. How these axes of difference then become sites of conflict, as well as opportunities for organizing across alliances, has not been considered by the NETs literature, but lessons from other examples are useful here. Forest carbon projects have increased intra-community conflicts, between richer and poorer households or those with power and access and those without; between men and women; between generations; and between different ethnic groups (Baynes *et al.* 2015, Benjaminsen and Kaarhus 2018, Kemerink-Seyoum *et al.* 2018), as well as risks of conflict within wider landscapes (Schmid 2022), with negative impacts on overall democratic decision-making among forest-dependent communities (Chomba 2017, Ece *et al.* 2017).

Yet in other cases, stronger community organizing has been an outcome of externally driven investments and dispossessions. Indigenous peoples' organizations have led successful efforts to frame REDD+ and other forest projects as a threat to identities and livelihoods if not designed with their rights in mind (Wallbott and Recio 2019, Marín-Herrera *et al.* 2021), while transnational framing and mobilization against land grabs and biofuels as a form of dispossession have successfully stopped some land appropriation attempts (Franco *et al.* 2010, Temper 2018). The combination of outside civil society/NGO support and the actions of cohesive user groups threatened by destructive development, such as for plantations or energy production, have proven decisive in many cases (Veuthey and Gerber 2012, Temper *et al.* 2020). Indigenous women in particular have been strong leaders in framing forest carbon projects as threats to household and community livelihoods, rights, and knowledges (Westholm and Arora-Jonsson 2018, Löw 2020). Food security and sovereignty angles around NETs have potential to be key pivot points for such organizing, particularly for land-competing NETs like afforestation or BECCS where increased food prices are predicted (Kreidenweis *et al.* 2016). High levels of uncertainty on how NETs will impact food access are thus likely to increase the sense of risk for many local communities.

<Table 2. Summary of Key Rural Issues across NETs>

Discussion: Challenges and Options for Anticipating NETs

The IPCC's 1.5° report has warned that 'The impacts of carbon dioxide removal (CDR) options on the Sustainable Development Goals (SDGs) depend on the type of options and the scale of deployment… Context-relevant design and implementation requires considering people's needs, biodiversity, and other sustainable development dimensions' (IPCC 2018) p. 21. This argues for reframing the use of NETs as a potentially high-risk gamble with serious justice implications, given uncertainties around deployment (Anderson and Peters 2016). Modeling projections suggest that the longer it takes to deploy NETs and the higher greenhouse gas emissions rise, the more NETs will be needed at a future point to avert serious climate damage (Skea *et al.* 2022). Thus if overshoot of 1.5° or 2° targets appears inevitable, the push to use multiple NETs is likely to accelerate (Muratori *et al.* 2020). Particularly for land-based NETs, many commentators see these as more benign and thus their deployment may be more likely, and support for NET technologies is likely to be correlated with their perceived naturalness (Buck 2019, Markusson 2022). This suggests likely more support for afforestation and less for BECCS, while in fact both strategies compete for land and might have similar agrarian consequences.

Yet for all the increasing discussions of NETs, they are not yet included in many country-level strategies for emissions reductions, including in the Nationally Determined Contributions (NDCs) required under the Paris Agreement. Afforestation and forest restoration is by far the most common NET in existing pledges; no country is currently on record as planning to engage in BECCS, and only a handful have noted their interest in other forms of CDR (see Table 3). This leads to a conundrum: IAM projections of pathways to keep emissions in line with 1.5° and 2° targets often include the use of NETs, while country strategies represented in NDCs rarely do so, outside of afforestation plans. The fact that models require NETs to reach temperature targets, while countries have few explicit plans to deploy them, runs the risk of a situation where there is a last-minute rush to expand these technologies, rather than carefully considering pros, cons, and research needs ahead of time (Moe and Røttereng 2018). It also has neglected a framing of 'who benefits' from use of NETs versus other approaches. In other words, "who gets to define what are legitimate mitigation and adaptation measures, involving which and whose natural resources, how, why and with what socio-economic and political implications?" (Borras *et al.* 2020)(p. 8) are not questions that most NDCs have yet asked.

<Table 3. NETs and NDCs>

Addressing the challenge of IAMs in normalizing NETs

As noted previously, nearly all IAM projections in IPCC reports to achieve a climate stabilization target well-below 2° require the inclusion of NETs of some kind (IPCC 2018), and there is increasing recognition that how policy options are framed in these models has serious influence on decision-making (Rogelj *et al.* 2019). Yet the opaque nature of modeling has led to misunderstandings of the role of NETs in these projections and in policy based on them (Fuhrman *et al.* 2019, Sovacool *et al.* 2019), with some scholars labelling modelers a 'geoclique' (Cox *et al.* 2018) or having 'an exclusive character' (Carton *et al.* 2020). To many, IAMs often operate like a black box where assumptions are unclear or unknown. The fact that the IAMs have normalized speculative options like BECCS is due to the fact there is simply no other way to produce a desired modelling result (keeping warming to 1.5°) without them (Low and Schafer 2020).

The empirical evidence from previous carbon forestry and biofuels projects provides evidence that land-based NETs can have detrimental consequences, yet many of these outcomes are not included in IAMs, despite increasing interest in ranking NETs across factors like feasibility, effectiveness, and side-effects to determine which portfolios to prioritize in coming decades (Rueda *et al.* 2021). For example, IAMs cannot model many known challenges like ethics and governance issues (Forster *et al.* 2020): they cannot answer where local populations are likely to be skeptical of NETs due to previous past poor performance of other rural schemes (Montefrio *et al.* 2015); and they do not yet consider issues like land tenure or biodiversity well. As a result, IAMs only model what they can – pricing, population, or land quality—and are silent on what they cannot. The modeling community has acknowledged that they need to do a better job incorporating 'implementation limits and obstacles' (Kriegler *et al.* 2014), as well as considering the 'impacts that NETs will have on sustainable development goals and equity issues' (Fuhrman *et al.* 2019). Surveys of IAM experts note that they see constraints around resource competition and political feasibility for most NETs, yet most still believe that land-based NETs are important to include in policy portfolios (Fridahl and Lehtveer 2018, Rickels *et al.* 2019).

Inputs from agrarian studies scholars' work could help introduce some improved indicators and constraints into IAMs. For example, conflicts over tenure rights and existing land grabs could be included by use of maps of land acquisitions risks in some spatially explicit IAMs. Including indicators related to employment and labor that would be required by different NETs as well as recognizing that these costs cannot be captured by carbon prices alone could also improve understanding. Recognizing the potential risks of NETs within IAMs (e.g., introducing variables around the possibility of lower-than-expected carbon capture or assuming that some percentage of NETs projects will fail) can provide a more realistic understanding of options as well. These improvements to IAMs could potentially reduce the problem of mitigation deterrence by being clearer that NETs are not a panacea and will often involve serious tradeoffs among sectors, regions and communities, many of which are yet to be captured in modelling (Grant *et al.* 2021).

Making NETs less negative through just approaches

As noted, most of the considerations of feasibility of NETs have focused on technical rather than social or justice elements (Morrow *et al.* 2020). Agrarian studies scholars can highlight problematic assumptions used in previous approaches, such as unclear marginal lands definitions that have influenced the deployment of biofuels (German *et al.* 2011). This work can also help temper the enthusiasm for NETs like afforestation as a low-hanging fruit of climate policy by highlighting the slow nature of policy change, given that design of carbon forestry to achieve co-benefits has taken decades and been very complex (vonHedemann *et al.* 2020). Indeed, the challenges faced in the past by voluntary forest carbon projects are likely to be even more significant for NETs, such as monitoring and accounting rules, which will have to account for the fact that biomass carbon sequestration may take place in one country and energy production in another (Brander *et al.* 2021).

NETs will likely need to have mechanisms for transparency, accountability, responsiveness, and legitimacy in order to be accepted and to reduce their impacts on rural communities. Attention to justice implications will mean that rural peoples need to be part of any discussions and alliances in sites of NET deployment: for example, procedural justice around siting of carbon capture facilities has been key to getting agreement from affected communities (McLaren 2012). Mechanisms for procedural justice, such as access to information and consent process around land acquisitions, have been used elsewhere (O'Beirne *et al.* 2020). For example, the engagement of local communities in design and implementation processes has been an important link between local actors and national goals in REDD+ projects (Schroeder & McDermott, 2014), which is a particular risk for BECCS given that feedstocks are likely to be produced in one place while energy generated elsewhere in long supply chains (Buck 2019). There is strong skepticism that voluntary codes of conduct or self-regulating mechanisms, such as those that have emerged around palm oil or soy biofuels, are likely to satisfy the need for procedural justice, arguing for stricter regulatory frameworks (Borras Jr and Franco 2010, Blaber-Wegg *et al.* 2015). This may include the acknowledgement of uneven risks by 'excluding some greenhouse gas removal options from certain regions, areas, or environments' (Smith et al. 2019, p. 277).

Distributional justice issues are also likely to play a key role in understanding who benefits from and who opposes NET deployment, including how benefit-sharing schemes are organized based on values or opportunity costs (Fisher, Bavinck, *et al.* 2018). To combat this problem, some biofuels policies have built in specific quotas or rights for smallholders, including ‘direct funding, low-interest loans, technical support, a guaranteed minimum price for biofuel feedstock, and a requirement that processors purchase part of their feedstock from smallholders’ (Hunsberger *et al.* 2017). NETs projects that ensure producers or users receive mandated benefits like clean electricity could also contribute to acceptability, as could expanded social safety nets as compensation if food prices rise, for example (Fujimori *et al.* 2018). Additional specific improvements across land, capital, labor, and politics to help minimize the impacts of NETs on rural communities that come from previous expiences are noted in the far right column in Table 2. These can include improving contracts for feedstock production or inclusion of food production alongside feedstocks; improving transparency in financing and contracting; instituting planning processes that ensure inclusion of affected communities; and explicit benefit sharing mechanisms. All these possibilities have been tested in previous forest carbon or biofuels policies with varying degrees of success, and will need to be contextually appropriate for the wide range of rural communities and local land uses affected by future NETs.

Conclusions

Recent reviews have noted that NETs are the latest in long line of ‘fads’ around land management, conservation, and climate change (Carton *et al.* 2020), and many are not likely to pan out given the lack of demonstration projects or ability to scale up at needed levels. Nonetheless, they are likely to remain important, both within IAMs and in the real world, and thus critical scholars need to engage with these concepts and projects (Beck and Mahony 2018, Brack and King 2021). The more that countries act now on climate mitigation, the less they must rely on uncertain NETs later on (Lenzi 2018, Hilaire *et al.* 2019), and research on the implications of NETs is an important part of decision-making in balancing these trade-offs, even as there are very real concerns about 'mitigation deterrence' in that the options to use any type of NET might create a moral hazard in diminishing the urgency of fossil fuel emissions reduction (Fuss *et al.* 2020, McLaren 2020). Ultimately, the key question is if the negative impacts of geoengineering or stringent mitigation policies are likely to outweigh the also very negative impact of a more than 1.5° world (Hasegawa *et al.* 2018, Robinson and Shine 2018), and how the uneven burdens of both scenarios might fall on more marginalized peoples. There is an additional ethical burden of asking future generations to resolve these thorny issues (Hansen *et al.* 2017), e.g., to decide between loss of coral reefs and other impacts versus the problematic future deployment of NETs (Vakilifard *et al.* 2021).

As shown in this review, many NETs that are land-based have potential to raise serious consequences for rural populations, including land tenure conflicts and dispossession, food security risks, gender impacts and poor working conditions, and inadequate benefit-sharing and uneven procedural justice. Many of these impacts are likely to fall hardest on poorer and more marginalized rural farmers and workers, and the land-competing NETs (BECCS and afforestation) are likely to be the most impactful. Additionally, rural populations that are not included, consulted, and given rights of refusal in NETs deployment are likely to influence whether these projects are able to be implemented, as rural protests and rejections of NETs may follow the paths of other climate interventions like forest carbon and biofuels, which have faced disapproval and even sabotage at local levels when faced with inadequate considerate of local values, rights, and benefits.

Given this review's focus on the gaps in knowledge around NETs, and strong evidence that questions surrounding land, capital, labor, and rural politics have been inadequately considered in existing discussions, there is a need for new transdisciplinary research agendas on

NETs to assess their technical, biophysical, financial, and societal uncertainties (Fuss *et al.* 2014, 2016, Minx *et al.* 2018). Critical social science literature is necessary to contextualize the difficulties that NETs are likely to face in deployment, whether top-down and large-scale or more community-based (Carton *et al.* 2020), including the ways in which rural peoples may resist or acquiesce to such interventions. Future research agendas are also needed around the use of IAMs in guiding decision-making, such as opening modelling to more participatory approaches and the recognition of alternative world views within them (Forster *et al.* 2020). Deliberative public engagement on research for these technologies can also help bring more democratic processes in and lead to better consideration of justice in NETs trajectories for the future (Low and Buck 2020).

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Table 1. Land-based NETs Potential Deployment, Impact and Costs

Type of NET	Description	Technical potential for CO_2 removal (flux) (Smith et al. 2020)	"Safe" deployment maximum potential (NAS 2019)*	Current scale of use	Potential scale of deployment	Creates competition for land?	Land required per ton of sequestered CO_2	Cost estimates $/t$CO_2$
BECCS	BECCS is the combination of bioenergy technology (e.g. production of electricity or fuels from biological sources, ranging from crops to trees) in which generated CO_2 is captured and stored on-site. In theory then, BECCS both draws down atmospheric CO_2 concentrations through biological growth and generates low-carbon energy. Rates of CO_2 removal depend on type of feedstock and scale at which bioenergy is produced, but BECCS has not yet been deployed in reality.	0.4-11.3 $GtCO_2\ yr^{-1}$	0.5-5 $GtCO_2\ yr^{-1}$	Only one demonstration facility in Illinois	Wide variation in estimates - 360-2400 Mha	Yes	Unclear	$45-250
Biochar	Biochar is a product of pyrolysis, which heats plant matter in absence of oxygen to 'lock-in' carbon and resist microbial decomposition. Anthropogenic soils with biochar are well-known from the Amazon (*terra prietas*). Biochar added to soil can persist for thousands of years, but total carbon removals require life-cycle analysis of production. Feedstocks can include a number of biological materials, from waste to purposively grown. Biochar has potential co-benefits for soil as it can increase water absorptive and	0.03-6.6 $GtCO_2e\ yr^{-1}$	0.5-2 $GtCO_2e$ yr	In US, 39,000 to 77,000 t/y biochar are produced and used	40-260 Mha	Some, for production of feedstocks	<1ha tC-1	0-$185

	nutrient status for crops and may reduce N2O emissions as well.							
Enhanced weathering and mineralization of CO_2	Mineralization occurs when silicate rocks are naturally weathered, and the CO_2 in the air converted to form carbonates like calcite (CaCO3) (NAS 2019). Use of mineralization as a NET has been suggested through various processes, including accelerated weathering of basaltic rocks, which would entail mining rocks, grinding them, and spreading them out on land to expose more surface area.	0.5-4 $GtCO_2$ yr^{-1}	2-4 $GtCO_2$ yr^{-1}	Only natural weathering in current use and some test sites	2 Mha and up to 680 Mha in tropics	No	~1t CO_2 t −1 of rock	$20-1000
Afforestation/ Reforestation (AF)	Afforestation is the conversion to forest of land that historically has not contained forests, while reforestation is the conversion to forest of land that has previously contained forests but that has been converted to some other use (Smith et al. 2020)	1.5-17 Gt CO_2e yr^{-1}	0.5-4 Gt CO_2e yr^{-1}	Widespread. Estimated that in 2000–2010 23.6 Mha was A/F; 2011–2019 added 3.1 Mha	Technical land potential up to 2,800 Mha, but more realistically 320-500 Mha	Yes	Depends on type and age of tree; ranges from <1ha per tC-1 to 40 tC-1 per ha	$0-100
Soil carbon sequestration	Organic carbon in the soil holds CO_2 and serves as a sink. This carbon content can be increased through land management practices (e.g. from annual cropping to perennial, or agriculture to forest); improved agricultural practices (cover crops, no-till); amending and improving the soil (adding manure, using different crops with deeper roots); and other means	0.4–8.6 Gt CO_2e yr^{-1}	Up to 5 Gt CO_2e yr^{-1}	Significant use of some land management techniques already; e.g. 10 Mha enrolled in US Conservation Reserve Program	Potentially up to several thousand Mha of existing land use, but realistically less	No	1–33 ha tC-1	<0-$100

Sources: (Moosdorf et al. 2014, Smith 2016, Beerling 2017, Griscom et al. 2017, Bernal et al. 2018, Minx et al. 2018, Sequestration et al. 2019, Fuss et al. 2020, Smith et al. 2020, Roe et al. 2021)

*"Safe" maximum rate of CO_2 removal as defined by the National Academy of Sciences means that "the deployment would not cause large potential adverse societal, economic, and environmental impacts" (NAS 2019). See also (Smith 2016)

Table 2. Summary of Key Agrarian Issues across NETs

Issue	Key research gaps in NETs literature	Problems identified in agrarian studies literature	Are these problems modelled in IAMs?	Main NETs affected	Potential improvements suggested by literature
Land	-Unclear definition of marginal lands for models - Impacts of displacement of existing land uses -Regional locations of NETs deployment -Risks of uncertainty around land tenure	-Land tenure conflicts -Land grabbing -Elite capture of land resources - Colonial histories and path dependencies	-Total area of deployment only. No inclusion of tenure, land conflicts, or risks of land grabbing.	BECCS, afforestation	-Improved contracts (more transparency, flexibility and oversight) -Inclusion of food production alongside NET feedstock production (e.g. agroforestry)
Capital	-Unclear carbon prices and their incentivization of NETs -Sources of funding (private vs public) -Overall costs of action over time - Risk of failures -Role of govt subsidies	- Role of financial speculation - Complications of measurement and verification -Transparency of contracting - Smallholder rights and costs	-Indirectly – carbon prices included, but not sources of funding	BECCS, weathering, soil carbon, afforestation, biochar	-Transparency in sourcing of investments -Improved contracts (more transparency, flexibility and oversight) -Investor safeguards on procedural and distributional justice - Mandated benefits, quotas, or price floors
Labor	-Types and quality of labor -Length of contracts -Gender issues -Risks to investors of labor violations	- Lower demands for labor due to mechanization - Stability of employment -Demands for migrant labor	No. Assumed adequate labor costs within carbon price	BECCS, afforestation, biochar	- Quotas for purchases from smallholders in outgrower models - Attention to gender concerns -Safeguards on labor rights - Expanded social safety nets
Rural politics	-Equity in benefit sharing -Perceptions of risks	- Procedural and recognition justice	Food price changes can be modeled, but not responses to these (e.g. food access).	BECCS, afforestation	-Participatory planning processes and attention to procedural equity

	-Impacts on food security	-Uneven benefit distribution - Conflicts over benefits -Rural coalitions and organization building in opposition	Concerns over social license to operate.		-Access to energy production and other shared benefits - Expanded social safety nets for those at risk of food insecurity

Table 3. NETs discussed in country NDCs

Afforestation	BECCS	Soil Carbon Sequestration	Enhanced weathering/ mineralization	Biochar	General mention of idea of NETs
Afghanistan Albania Algeria Angola Armenia Bahrain Bangladesh Belize Benin Brunei Cabo Verde Cambodia China Comoros DRC EU Eritrea Ethiopia Gambia Georgia Ghana Guinea Iceland India Indonesia Jordan Kenya Kyrgyzstan Lebanon Lesotho Liberia Malawi Mexico Moldova Morocco Myanmar Namibia Niger Nepal North Korea	None	Zambia Malawi UAE Liberia China	Iceland	Belize Namibia Myanmar	Canada Fiji

Pakistan Palestine Papua New Guinea Rwanda Samoa Sierra Leone Sri Lanka Somalia South Sudan St. Vincent and Grenadines Sudan Tajikistan Tanzania Turkey Uruguay Uzbekistan Uganda Vietnam Zambia					

Source: Search of NDCs submitted to UNFCCC.

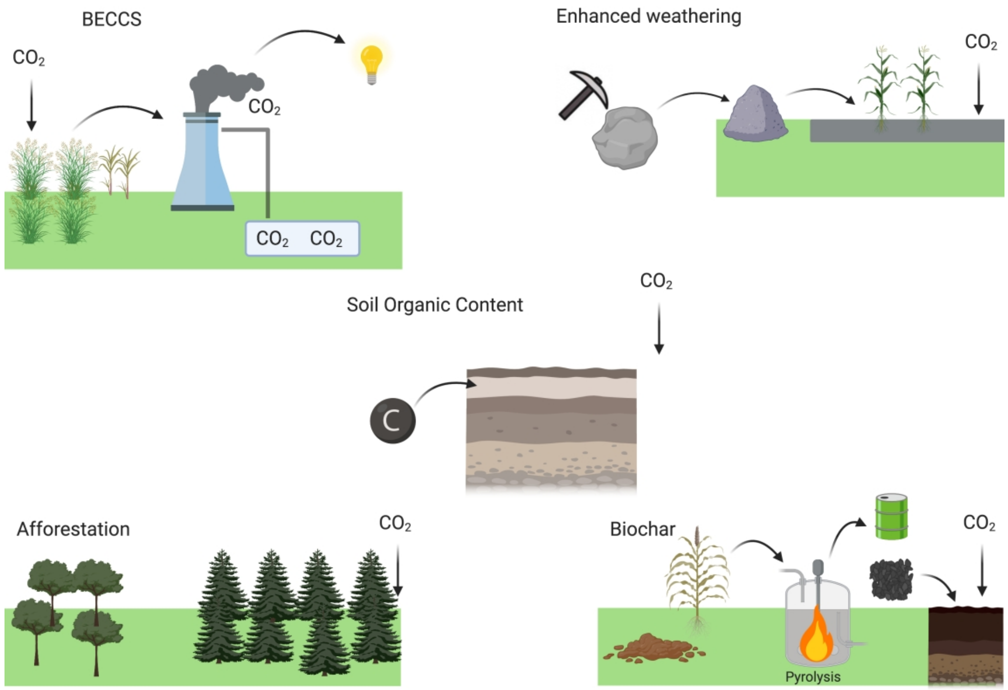

Figure One – Major land-based NETs

645x452mm (118 x 118 DPI)