A review of scientific literature on the climate impacts of forest biomass use

Ruben Lubowski and Gabriela Leslie[1]

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Introduction

A priori carbon neutrality assumptions are contrary to the scientific consensus.

The EPA's policy statement of April 23, 2018 titled "Treatment of Biogenic Carbon Dioxide (CO_2) Emissions from Stationary Sources that Use Forest Biomass for Energy Production" states that, for the purposes of forthcoming regulatory action, all biomass combustion from managed forests at stationary sources for energy production will be considered carbon neutral. In doing so, the EPA disregards scientific consensus that energy derived from forest biomass, whether from managed forests or otherwise, is not necessarily "carbon neutral." Rather, the net greenhouse gas implications of using forest biomass for energy depend on factors such as the current and prior land-use and management practices, the production region, the feedstock type, and the appropriate spatial scale and time horizon for the assessment. Depending on such factors, energy production from forest biomass has the potential to reduce net emissions—as well as to increase net emissions—relative to the use of fossil fuels (Searchinger et al. 2009; Haberl et al 2012).

Forest biomass and other biogenic fuels, just like fossil fuels (i.e. fuels derived from biomass fossilized over geological timeframes), emit carbon emissions when combusted. However, in contrast to underground reserves, which are unchanging over relevant timeframes, forest and agricultural landscapes are absorbing (sequestering) carbon, both above and below ground, as plants photosynthesize and grow. They also emit carbon through both respiration and the decomposition (oxidation) of leaves, litter and other organic matter. As feedstocks for bioenergy are drawn from organic matter on these landscapes, biogenic fuels have the potential to impact net carbon emissions in ways that go beyond just the emissions from the combustion of the fuel.

The logic is as follows. Through changing the rates of photosynthesis, respiration, and decay on a landscape, feedstock production and harvest for bioenergy can, but does not have to, alter the net carbon flux from a region in comparison to what otherwise would have occurred in the absence of that bioenergy production. In some cases, bioenergy feedstock production could reduce net emissions by increasing absorption (i.e. by changing land use or management practices to increase carbon storage) and/or by reducing gross emissions (i.e. by capturing decomposing materials), relative to a baseline of what otherwise would have likely occurred. A net gain in sequestration as a result of feedstock production is not a given, however. The same processes that drive net sequestration can also alter carbon stocks in the opposite direction, driving an increase in net emissions from the landscape——for example if a new forest

[1] Ruben Lubowski is Chief Natural Resource Economist at Environmental Defense Fund. Gabriela Leslie is a Research Analyst at Environmental Defense Fund.

management regime lowered the carbon stocks on the landscape, relative to what otherwise would have occurred.

Therefore, in order to correctly evaluate the net emissions impacts of bioenergy use and be confident in the climate mitigation benefits delivered by bioenergy feedstocks, one must consider not only the feedstock type, production,and harvest method, but also the scale of assessment, the timeframe over which gains and losses are considered, and what would have happened on the landscape in the absence of production and harvest.

As biomass production, particularly forest biomass, is often part of an economic and/or management system that spans over a landscape, rather than an individual stand, care must be taken to select a geographic scale of assessment that is representative of the landscape-level production and harvesting regimes distinct to the type of biomass in consideration (Cintas et al 2017). The geographic scale used for the assessment of the performance of bioenergy feedstock production systems will impact the net emissions impacts, relative to fossil fuels (Galik et al 2012; Pingoud et al 2012; Sathre and Gustavsson 2011; Schlamadinger et al 1995). Focusing on too small a scale can over- or under-estimate the total carbon stock changes and available harvest supply of the production region. On the other hand, focusing on too large a landscape (e.g. the entire country or the world) may be too expansive to reflect the impacts associated with feedstock production in a particular region. For instance, a case study assessing forestry in the Northeastern forests of the United States found that assessments of forest productivity at the site or stand level, rather than the regional level, typically over-estimates overall forest productivity, and thus the total volume of feedstock available for harvest without negatively impacting the standing stock of carbon (Buchholz et al 2011). To speak of carbon neutral biomass production without specifying and justifying the scale over which such assumptions apply is incomplete.

In addition, the timing over which changes in carbon stocks occur also matters when specifying which bioenergy feedstocks are appropriate options to reduce the carbon intensity of fuel consumption. Even if using forest biomass for energy eventually produces no net change in carbon stocks or a net increase in carbon stocks on the appropriate landscape, this gain must occur within a timeframe relevant to the identified climate goal, in order for bioenergy to have less of an impact on atmospheric concentrations of greenhouse gases than other fuel sources. For example, the timeframe required to preserve a chance at meeting the 1.5 degree Celsius temperature rise target as laid out in the Paris Agreement is short—the Intergovernmental Panel on Climate Change (IPCC) estimates that nations will have to make substantial reductions in emissions rates by 2030 to meet such targets (IPCC 2018). Therefore, the extent to which bioenergy can be used to meet such targets will depend on the timeframe required for net carbon benefits to accrue.

Some authors have argued that while forest biomass harvest may create an initial spike in near-term carbon dioxide (CO_2) emissions, they typically do produce net climate gains relative to fossil fuel combustion over timelines that are relevant to avoid the worst effects of CO_2 accumulation (Miner et al 2014). However, for some forest types and/or regions, the regeneration of forests following harvest can take many decades to centuries, with emissions contributing to dangerous warming effects in the interim (Gibbs et al 2008; Holtsmark 2012;

Mitchell et al 2012; Pingoud et al 2012). For such harvesting types and intensities, the net impact on greenhouse gas emissions from burning the additional biomass harvested will persist for long periods, making their use for bioenergy roughly equivalent to burning fossil fuels for many decades (Lamars and Junginger 2013; McKechnie et al. 2011; Miner et al 2014; Mitchell et al. 2012; Walker et al 2013).

Even if managed forests with faster growing species are more intensively harvested, it could still take decades to realize any significant net benefit to the climate relative to burning fossil fuels, exceeding the restrictive timelines required to avoid the worst impacts of climate change as well as the timeframes set by particular policy processes (e.g. the goal under the Clean Power Plan to reduce CO_2 emissions from power generation by 32 percent by 2030, relative to 2005 levels). It is also important to note that many forests would still have continued to stock carbon due to natural growth processes in the absence of bioenergy feedstock production or harvest (Fargione et al 2008; Johnson and Tschudi 2012, Mitchell et al 2012). In such cases it is not appropriate to count any increased carbon storage on lands not under management when considering stock changes associated with managed lands. Moreover, to omit the counterfactual growth in carbon stocks in the absence of bioenergy feedstock production could over-inflate the net carbon benefit of feedstock harvest.

It thus is not meaningful to refer to bioenergy as carbon neutral without specifying the feedstock and geographic region in which it was produced and the time period over which carbon neutrality is estimated. More generally, the question is not simply whether or not using biomass for energy leads to a net greenhouse gas reduction over a particular timeframe relative to using fossil fuels—it is also *to what extent*. Some biogenic fuels may exhibit lower emissions totals than fossil fuel combustion, but not reach full carbon neutrality, while in other cases feedstocks could even be carbon negative. Nevertheless, due to the possibility of only partial emissions reductions, coupled with the length of time needed to produce a carbon-beneficial result, if any is produced at all, biomass use may not be an appropriate method of reducing greenhouse gas emissions in time to avert severe warming impacts by mid or late century or to meet nearer term emission reduction targets. Therefore, bioenergy feedstocks with longer timeframes for re-sequestration may compromise efforts to stay on track with such goals.

Even if forest biomass feedstocks produce a net emissions benefit over a landscape, there are also other dynamics that affect the extent to which biomass feedstocks can mitigate warming trends. These include other climatic feedbacks such as albedo and cloud formation, as well as market-driven feedbacks that can erode potential climate benefits by increasing harvests or forest conversion in ways that increase emissions in other parts of the country or world. Such drivers further point to the need for context-specific feedstock evaluation in contrast to blanked carbon neutrality assertions.

Critiques of the EPA's Justifications for a Blanket Carbon Neutrality Stance

The EPA makes a number of points that attempt to contextualize and justify the carbon neutrality stance within the text of its published Statement. Most notably, the EPA attempts to constrain the scope of the EPA's proposed carbon neutrality stance to "managed forests" only. However, this definition in itself does not justify a blanket carbon neutrality position. In its Policy Statement, the EPA defines the forests covered by the carbon neutrality assumption as “a forest subject to the process of planning and implementing practices for stewardship and use of the forest aimed at fulfilling relevant ecological, economic and social functions of the forest (IPCC)… it specifically comprises lands that are currently managed or those that are afforested, to ensure the use of biomass for energy does not result in the conversion of forested lands to non-forest use.”

There are two main concerns with this definition. First, managing for “ecological, economic, and social functions” does not necessarily mean managing for the carbon content of a forest. There are many management strategies that bolster ecological, economic, and social functions and that could furthermore also be “sustainable,” but that diminish the carbon stock on the landscape both in the near and longer terms. For example, this includes shifting a more mature forest to a lower average aged, more frequently harvested system. Second, conversion of old-growth forests to managed forest plantations has also been shown to diminish the carbon content of the land (Fargione et al 2008; Gibbs et al 2008; Mitchell et al 2012). Under the EPA’s current definition, such forest conversions are theoretically eligible for inclusion under its blanket carbon neutrality policy. None of these scenarios would generate biomass feedstock that would be carbon neutral a priori.

The EPA even acknowledges that the science runs contrary to their stance within the text of their published statement, stating that “The SAB peer review of the 2011 Draft Framework[2] found that it is not scientifically valid to assume that all biogenic feedstocks are carbon neutral, but rather that the net biogenic carbon profile related to the use of biomass feedstocks depends upon factors related to feedstock characteristics, production and consumption, and alternative uses” (EPA 2018). Indeed, many of the considerations they list as contributing factors in their decision-making process make it clear that the climate impacts of biogenic fuels are dependent on specific harvest and management conditions, not on forest biomass writ large.

The EPA Policy Statement also goes on to cite a number of justifications informing their decision, one of which pertains to the market feedback effects that it assumes will help promote better forest management within the United States, stating “recent research shows that under current market and environmental conditions, continued forest land investment and management can allow for continued and even increased U.S. forest carbon stocks in the future” (EPA 2018). While this “*can*” be the case, as EPA notes, this is not necessarily the case.

EPA cites Tian et al. (2018) to support the point that greater demand for biomass feedstocks can increase the carbon stocks of managed forestland in the US, but other studies find that impacts need not be carbon positive. Some studies suggest that increased forest biomass demand will be partially met by the wood products market instead of increased forest area, such that there is no net gain, or by an increase in harvest frequency and intensity, which may result in decreased carbon stocking relative to less intensive harvesting methods (Böttcher et al 2011; Miner et al

[2] EPA Science Advisory Board Review of the 2011 Draft Accounting Framework for CO_2 Emissions for Biogenic Sources Study (2012) <https://yosemite.epa.gov/sab/sabproduct.nsf/0/57B7A4F1987D7F7385257A87007977F6/$File/EPA-SAB-12-011unsigned.pdf>.

2014; White et al 2013). It is currently unclear that increased demand will uniformly increase forested area or carbon stocks on preexisting forestland. Thus, the potential for climate-beneficial market effects alone are not a sufficient justification for a blanket carbon neutrality stance.

Lastly, the EPA seeks to justify its carbon neutrality assumption under the premise that it will foster easier alignment with regional regulatory regimes:

> "An EPA policy treating biogenic CO_2 emissions from the use of biomass from managed forests at stationary sources for energy as carbon neutral, as presented in this document, will foster the alignment of EPA regulatory actions with the treatment of biogenic CO_2 emissions in U.S. state and international programs. For example, the California Cap-and-Trade Program[3] and the Regional Greenhouse Gas Initiative (RGGI)[4] among Northeast and Mid-Atlantic states exempt biogenic CO_2 emissions from a compliance obligation, provided that specified types of biomass are used that meet certain requirements. In addition, the European Union Emission Trading Scheme (EU ETS)[5] exempts biogenic CO_2 emissions at stationary sources from a compliance obligation." (EPA 2018).

While the California Cap-and-Trade Program and the RGGI trading schemes do indeed exempt biomass combustion from a compliance obligation, that does not mean that there is consensus that this approach is valid, evidenced by criticism from stakeholder coalitions, such as those penned in an open letter to the California Air Resources Board (CARB) (Nowicki et al 2011). Moreover, in California, biomass that is exempt from compliance still has a mandate to report emissions and sequestrations under reporting standards established by CARB (CARB 2018). Therefore, forest biomass is not assumed to be necessarily carbon neutral such that it is exempt from reporting requirements.

It is also noteworthy that the variable net climate impacts of alternative biogenic feedstocks are explicitly recognized under the federal government's and California's policies for liquid biofuels, including from cellulosic feedstocks, under the Renewable Fuel Standard (RFS) and Low Carbon Fuel Standard (LCFS), respectively.

There is also not uniform exclusion of forest bioenergy emissions from carbon pricing systems at the international level. For the past decade, New Zealand, one of the pioneers in carbon pricing, includes all forest carbon within its emissions trading system and requires landowners to pay for carbon removal from their land (as well as crediting sequestration). In fact, the forest sector was the first sector regulated under this program, starting in 2008 (EDF, Motu, IETA 2016).

Furthermore, the European Commission's Joint Research Center chartered a report in 2013 to assess the state of biofuels in their climate objectives, and found that reporting standards were "more the result of static and incomplete accounting/reporting of carbon stocks flows rather than a physical reality." (Agostini et al 2013). The report also found that "In the case of dedicated harvest of stemwood for bioenergy purposes and short term GHG reduction policy objectives

[3] https://www.arb.ca.gov/cc/capandtrade/capandtrade.htm
[4] https://www.rggi.org/
[5] https://ec.europa.eu/clima/policies/ets_en

(e.g. 2020) the assumption of "carbon neutrality" is not valid since harvest of wood for bioenergy causes a decrease of the forest carbon stock, which may not be recovered in short time, leading to a temporary increase in atmospheric CO2 and, hence, increased radiative forcing and global warming." (Agostini et al 2013)

In fact, the European Council and Parliament has recently released revised standards for the land use, land use change, and forestry sector, stating that the sector will be fully included within 2030 climate objectives after 2020 and resolving some of the accounting insufficiencies inherent in the previous rulebook (Grimault et al 2018).

In sum, judicious use of forest-derived biomass for energy production can support rural economies, help sustain forested landscapes, and can reduce net greenhouse gas emissions relative to fossil fuels over policy relevant timeframes. Nevertheless, the amount of variation in the potential climate impacts of forest bioenergy makes a blanket policy such as the one proposed by the EPA scientifically invalid.

<u>Technical Summary</u>

Bioenergy feedstock production and harvest can alter carbon stocks on production landscapes.

Vegetated landscapes are not static systems—the carbon stored in such landscapes cycles through various carbon pools, such as that within aboveground living plant matter (stemwood, branches, non-woody flora), belowground living plant matter (root systems), soil carbon, and deadwood, plant residues, and leaf litter. As such carbon pools are inter-dependent, removing or altering biomass linked to any one of such carbon pools can change the total carbon stock of the harvest landscape, over either the short- or long-term.

Production and removal of woody biomass for fuel production changes the dynamic carbon balance of a harvest landscape. Assessing the net impact such biomass production and harvest has on landscape-level carbon stocks both above- and below-ground, requires assessing two things: first, direct changes in carbon volumes over at least one complete harvest cycle relative to past uses, and second, the counterfactual impact of how much carbon would have continued to accumulate on that land in the absence of harvest (the "alternative fate").

Assessing the changes in carbon stocks relative to past land uses is usually straightforward: if a landscape is converted from old-growth forest to high-yield plantations, carbon stocks will typically be lower as a result of biomass production than they were in the past, leading to biomass plantations becoming a net carbon source (Fargione et al 2008; Gibbs et al 2008; Searchinger et al 2009). However, if fallow or low-value agricultural land is converted into a well-managed biomass plantation, the net carbon stocks on that land may increase, making such feedstocks viable carbon sinks (Fargione et al 2008). Thus, in certain situations, the potential of management activities to increase the amount of above-ground carbon uptake on a site can be substantial (Canadell and Raupach, 2008; Pyorala et al 2012). In other cases, management practices, such as fuel-reduction treatments aimed at mitigating wildfire risk that reduce the amount of on-site biomass, can substantially decrease the amount of carbon stored within a forest stand, and, in the aforementioned example, may not necessarily pay off in avoided carbon losses from wildfires (Cherubini et al 2011; Lippke et al 2011; Holtsmark, B 2013; Hudiburg et al 2011; Mitchell et al 2009). Thus, when seeking to use bioenergy to mitigate carbon emissions, one must differentiate between biomass production that reduces net aboveground carbon stocks relative to past uses and one that increases aboveground carbon stocks.

In addition, one must consider the forecasted future carbon sequestration that would have occurred across a production region in the absence of production and harvest (the “alternative fate” of the biomass). For example, if a forest is harvested for bioenergy feedstock in a manner that keeps net carbon stocks on the landscape stable, one must consider whether the forest, left untouched, would have continued stocking carbon during the maturation process. If so, the difference between what the landscape would have sequestered when unmanaged versus what it would sequester under production or harvest scenarios must also be considered as part of a biomass feedstock’s net greenhouse gas impact (Fargione et al 2008; Johnson and Tschudi 2012, Mitchell et al 2012).

As it stands, the proposed stance as outlined in the EPA’s Policy Statement does neither. It categorizes all forested lands only by whether or not they follow a loose definition of being “managed forests,” which is not specific enough to differentiate between harvest regimes that reliably stock carbon and those that remove carbon, let alone assess the counterfactual impact of those harvest practices.

In addition, the EPA’s Policy Statement makes no mention of the recommend scale of assessment that EPA intends to use to determine whether managed forests fit under their umbrella of “carbon neutrality.” Under a rigorous approach to forest landscape assessments, care must be taken to select a scale of assessment that is representative of the landscape-level land use changes associated with biomass management and harvesting regimes (Cintas et al 2017). Focusing on too small a scale can over- or under-estimate the total carbon stocking rates and available harvest supply of the production region.

While important, changes in aboveground carbon are not the only consideration when assessing the carbon stock changes of a harvest landscape. One must also assess changes in belowground carbon as a result of harvest practices.

In systems where initial soil carbon storage is high, conversion of land for biomass production is likely to generate net soil carbon losses, whereas converting sites with low initial soil C, such as conventional cropping systems, has the potential to enhance soil carbon stocks (Cowie et al 2006). Other studies have pointed out that harvest residue management practices can significantly alter soil carbon pools, either positively or negatively depending on circumstances (Chen and Xu 2005; Helin et al 2013; Helmisaari et al 2011; Jones et al 2008; Jones et al 2011; Kirkinen et al 2008; Nave et al 2010; Powers et al 2005; Smaill et al 2008; Zanchi et al 2010). Pre-existing forest stand conditions can affect how sensitive the soil carbon stocks of sites are to biomass removal practices, such as the mineral soil texture, microclimate, and availability of other soil nutrients (Thiffault et al 2011). Schulze et al (2012) further note that harvest residue removal may subsequently require fertilizer inputs to make up for lost nutrient inputs from natural decomposition, thus potentially increasing on-site nitrous-oxide emissions from fertilizer.

Other studies have countered that while soil carbon stocks may be altered by harvest practices, on average the overall volume of carbon loss is more than made up for by increases in above-ground carbon stocks, accumulated harvest over time, or fossil-fuel displacement (Berndes et al 2012, Cowie et al 2006; Johnson and Curtis 2001). Still others have mentioned that while initial soil carbon stocks may change as a result of biomass harvesting, long-term changes in soil carbon are likely to be negligible—but make this assumption only under conditions of specific, sustainable harvest techniques which are not generalizable (Lippke et al 2011, Malmsheimer et al 2011).

Even so, in all cases the effect of biomass harvest on soil carbon is non-zero, and thus cannot be called carbon neutral without further examination. The extent to which the net changes in soil carbon storage last over time or are of a magnitude large enough to overcome other net changes in aboveground carbon storage is not inherent—it is dependent on distinct management choices and may vary widely across regions and production systems.

Land Conversions

The type of land that may be converted for biomass production or harvest varies in its carbon density, and thus mediates the emissions implications over time of biomass feedstocks harvested on those lands. For example, numerous studies have shown that biomass crop expansion into productive tropical ecosystems and other old-growth landscapes will lead to large carbon losses and thus create net carbon emissions for decades to centuries (Fargione et al 2008; Gibbs et al 2008; Mitchell et al 2012). Biomass harvest in mature boreal forests may also produce negative impacts for hundreds of years (Holtsmark, B 2012). On the other hand, converting degraded or previously cultivated land to biomass production can provide almost immediate climate benefits, due to the fact that such conversions typically increase the total amount of carbon sequestered on such lands (Fargione et al 2008; Gibbs et al 2008; Mitchell et al 2012).

Feedstock Types and Decomposition Rates

Net emissions impacts over time can vary based on feedstock type as well. The projected future use of a feedstock (either due to its use in product markets, combustion, or decomposition) can mediate whether its use for biomass creation generates emissions that persist in the atmosphere for long or short durations. There can be considerable variability of such GHG impacts between different feedstocks types (Canter et al 2016). In the case of harvested biomass products that otherwise would have been left on-site to decay, the rates of decomposition alter their net GHG impacts over time, by determining their counterfactual emissions profile and thus the potential carbon benefit to using such feedstocks for bioenergy (Miner et al 2014; Repo et al 2012; Zanchi et al 2010). On-site decomposition is associated with a distinct rate at which residues emit stored carbon into the atmosphere, as well as with the fraction of their stored carbon that is incorporated into soils or other biomass growth on the stand as opposed to being released as atmospheric emissions. To omit such decomposition dynamics of removed products for bioenergy from empirical assessments of the climate impact of biofuels may under- or over-estimate the emissions impact of such fuel sources. A discussion of a number of distinct feedstock types is included below.

Harvest and Mill Residues

Forest or agricultural harvest residues typically remain decomposing on fields or are combusted as waste byproducts (Miner et al 2014). If such residues would have otherwise been decomposed over a very short period of time or burned on-site, diverting such residues for fuel production can produce near-immediate climate gains (Jones et al 2010; Miner et al 2014). Similarly, mill residues were historically incinerated on-site or sent to landfills, thus using such residues for fuel can have zero or even less than zero climate impact (resulting from methane release in landfills) relative to alternative uses (Gaudreault and Miner 2013; Miner et al 2014).

Harvest residues that are left to decompose over a longer time frame, on the other hand, do not provide immediate climate benefits when they are used to produce energy. In most cases, combustion of residues that would have otherwise decomposed releases carbon into the atmosphere at a faster rate and a greater share than otherwise would have been emitted through natural decomposition, affecting the timeline of emissions and removals as a result of biomass harvest (Repo et al 2012; Zanchi et al 2010). The relative impacts of using such residues as energy feedstocks depend primarily on expected decay rates (Lamars and Junginger 2013). While rates vary depending on region, weather conditions, and biomass type, researchers have pointed out the majority of logging residues in the US have a half-life of under 50 years (Miner et al 2014; Radtke et al 2009; Russell et al 2014; Zimmerman 2004). While not showing immediate carbon benefits, using such residues for fuels has the potential to generate some net emission reduction benefits relative to fossil energy use, if an appropriate time horizon is used. In other cases, relative impacts can be even higher if decay rates are slower than regional averages—but in most cases using forest residues for bioenergy can achieve net emissions reductions within a few decades, varying depending on the type of fossil fuel displaced by biofuel use (Miner et al 2014; Pingoud et al 2012; Sathre and Gustavsson 2011; Zanchi et al 2012).

Even so, it must be noted that even in the case of residues with relatively short timelines for achieving net GHG benefits, their climate impacts are not zero. The co-emissions from collection, transport, and refining, along with the time combusted emissions circulate in the atmosphere prior to re-uptake, all contribute to near-term warming. Therefore, such residues can reasonably be termed as having lower emissions relative to fossil energy, but not as immediately carbon neutral fuel sources.

Other Forest Feedstocks

Roundwoods and large trees have slower re-growth pathways and larger carbon stocks released through combustion. When examined at a small spatial scale, the near-term warming effects from using these feedstocks for energy production may rival those of fossil fuels, and take many decades to realize climate benefits (Lamars and Junginger 2013; McKechnie et al. 2011; Miner et al 2014; Mitchell et al. 2012; Walker et al 2013). In these cases, the utility of using such roundwoods for biofuels in order to meet near- and medium-term climate targets could be limited, but this will depend on the overall performance of the production region, as noted below. On the other hand, faster-growing species cultivated on lands with improvements in forest productivity may have a lower climate impact than fossil fuels, but their benefits depend on whether foregone sequestration was included in calculations of net climate impact (Miner et al 2014).

In sum, one cannot assess the true warming impacts of biogenic fuels without evaluating re-growth timeframes (Kirkinen et al 2008; Levasseur 2012; Pingoud et al 2012; Sathre and Gustavsson 2011; Schlamadinger et al 1995; Walker et al 2013). However, one must consider the scale of assessment as well. If a single stand of trees is harvested and evaluated for carbon impact, but the production system encompasses a system of multiple tree stands managed for regrowth and harvest yield, evaluations of the net carbon impact and timeframes of carbon gains resulting from production require a broader scale of assessment, or otherwise will be skewed (Cintas et al 2017; Galik et al 2012). For instance, a case study assessing forestry in the United States Northeastern forests found that assessments of forest productivity at the site or stand level, rather than the regional level, typically over-estimate overall forest productivity, and thus the total volume of feedstock available for harvest without lowering total carbon stocks on the landscape (Buchholz et al 2011).

While certain regions and feedstock types may perform better relative to others, when assessed at an appropriate scale, few biomass feedstocks exhibit carbon neutrality over 100 year timelines, let alone over 10-, 20-, or 30-year timelines that are most relevant for near- and mid- term climate mitigation policy targets.

Beyond Carbon: Climate Effects of Changes in Land Surface Properties.

When considering the climate impact of biomass feedstocks, one must also consider other climate forcing feedback effects that accompany such production methods, beyond the direct emissions tracked by "carbon-only" accounting practices (Agostini et al 2013). For example, forestry projects can change the properties of the land surface that mediate energy transfer to the atmosphere, like albedo, surface roughness, and evapotranspiration (Anderson et al 2010; Jackson et al 2008). These land surface properties affect the climate at different scales, and have the potential to either enhance or counteract the climate benefits from forest carbon sequestration (Bright et al 2012; Marland et al. 2003).

In general, forested areas have greater surface roughness and lower albedo than the land cover they replace, which increases the amount of light and heat absorbed by the land surface and more effectively transferring energy from the land surface to the atmosphere via convection (Betts 2000; Bonan 1997). In addition, the amount of water availability in a region, plus the co-emission of organic carbon compounds like terpenes that act as condensation nuclei for clouds, can mediate low-altitude cloud formation over a forested area, influencing regional surface reflectance and thus warming or cooling effects (Anderson et al 2010; Kumala et al 2004; Spracklen et al 2008; Werth and Avissar 2002). Thus, in water-limited environments, afforestation of land, particularly with coniferous trees as opposed to deciduous trees, may have a net local warming affect due to decreased albedo and lower rates of evapotranspiration (Anderson et al 2010; Betts 2000; Field et al 2007; Jackson et al 2008; Liu and Randerson 2008; McMillan and Goulden 2008).

Whether these climate feedbacks are ample enough in temperate or boreal regions to counteract the net cooling effect of carbon sequestration is still not conclusive. However, a number of studies have made the case that large reforestation in boreal or northerly temperate regions may have a nearly neutral or even net warming effect, by substituting snow-dominated regions for dark forest canopies with higher surface roughness (Anderson et al 2010; Betts et al 2000; Canadell and Raupach 2008; Schwaiger et al 2010; Thompson et al 2009). On the other hand, there is a general consensus that ceasing tropical deforestation and promoting tropical afforestation has the clearest climate benefit of any such projects, due to high carbon storage averages per unit area, relative water abundance, and large global surface area (Anderson et al 2010; Bala et al 2007; Canadell and Raupach 2008; Grace 2004; Jackson et al 2008; Thompson et al 2009).

Thus, while land surface properties may not directly affect the net emissions, they will be critical in influencing the overall climate impacts of large-scale forestry projects. Therefore, to the extent that biomass feedstocks are being used to achieve climate goals, such effects should not be ignored.

Market Feedback Effects.

Another topic of discussion pertains to the market feedbacks of increased demand for biomass use. Some authors have concluded that increasing demand for woody biomass feedstocks can help stimulate increased production of such fuels, thus potentially increasing the land surface area devoted to forestry and plantations and increasing the amount of carbon stored on such lands (Miner et al 2014; Sedjo and Tian 2012).

Nevertheless, others contend that the market effects of increased demand will primarily come from wood displaced from the wood products market, while increases in harvested wood will be small (Böttcher et al 2011). Still others have pointed out that increased demand may only partially be met by forest area expansion – another portion of that demand may be met by increasing biomass harvest intensity and frequency, possibly decreasing the total carbon stocks on the land below what they would have been otherwise (Miner et al 2014; White et al 2013). In addition, intensive forestry management may require increased fertilizer use and larger tailpipe emissions from transport vehicles and machinery than unmanaged forests, potentially compromising the climate benefits of higher carbon stocking rates (Anderson et al 2010). Taken altogether, it cannot be said there is a clear scientific consensus that increased use of forest biomass for biofuels will be a reliable mechanism for increasing the carbon stocks of managed forest. Thus, the EPA should take care not to over-emphasize or misconstrue this potential effect in further planning documents.

Lastly, the largest risk in considering all forest biomass used for energy as net carbon neutral irrespective of their source or crop type is that there will be large-scale demand for woody biomass from primary forest, or increased incentive to convert land from natural terrain to bioenergy crops, irrespective of the actual emissions associated with such changes (Searchinger et al 2010). Such indirect emissions from land use change have the potential to be substantial.

In sum, market mediated effects of biomass demand on overall forest carbon stocks are likely to be regionally specific and thus are difficult to generalize and depend on the magnitude of demands.

Conclusion

Treating forest biomass used for energy production as uniformly carbon neutral does not reflect the underlying science regarding the climate impact of such feedstocks. The total carbon stored by such landscapes is variable, rather than fixed, and the carbon stocks of soils and aboveground biomass will vary depending on management practices, crop type, and frequency of harvest. Moreover, landscape changes and choices made during feedstock production or harvest can have climate effects beyond those driven by total carbon sequestered in stands, either due to biophysical drivers (such as land surface changes and evapotranspiration), or due to market drivers (such as increased fuel use for harvest machinery or conversion of high carbon stock primary forest into managed plantations).

Not all biomass feedstocks used for energy are thus equal from a climate perspective, and climate impacts can be positive or negative by varying degrees and over different time frames compared to fossil energy use. While using some forest feedstocks (e.g. mill residues) for energy production will have net climate benefits over relatively short time frames compared to fossil energy use, the carbon neutrality of forest-derived bioenergy use—and more relevantly, its net climate impacts over a particular time horizon—must be determined on a case- and feedstock-specific basis, rather than assumed a priori.

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