Energy Policy 110 (2017) 434–446

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Does the world have low-carbon bioenergy potential from the dedicated use of land?☆

Timothy D. Searchinger[a,*], Tim Beringer[b], Asa Strong[c]

[a] Princeton University, Princeton, NJ 08544, USA
[b] Mercator Research Institute on Global Commons and Climate Change, Berlin, Germany
[c] World Resources Institute, Washington D.C., USA

ARTICLE INFO

Keywords:
Bioenergy
Carbon sequestration
Climate change
Greenhouse gases

ABSTRACT

While some studies find no room for the dedicated use of land for bioenergy because of growing food needs, other studies estimate large bioenergy potentials, even at levels greater than total existing human plant harvest. Analyzing this second category of studies, we find they have in various ways counted the carbon benefits of using land for biofuels but ignored the costs. Basic carbon opportunity cost calculations per hectare explain why alternative uses of any available land are likely to do more to hold down climate change. Because we find that solar power can provide at least 100 times more useable energy per hectare on three quarters of the world's land, any "surplus" land could also provide the same energy and mitigate climate at least 100 times more if 1% were devoted to solar and the rest to carbon storage. Review of large bioenergy potential estimates from recent IAMs shows that they depend on many contingencies for carbon benefits, can impose many biodiversity and food costs, and are more predictions of what bioenergy might be in idealized than plausible, future scenarios. At least at this time, policy should not support bioenergy from energy crops and other dedicated uses of land.

1. Introduction

Estimates of potential low or zero carbon bioenergy can be 500 EJ or higher even as authors assume bioenergy will not displace food or wood products (Chum et al., 2011; Creutzig et al., 2015). Dedicated energy crops provide the largest estimated sources, with some estimates also based on harvesting wood from forests. We call these sources bioenergy from "dedicated use of land" because they require the dedication of some or all the productive capacity of land even if some harvested wood, crop or biofuel by-products continue to serve other uses.

These large estimates of bioenergy from such dedicated uses of land raise attention because of their competition for land and biomass:

- One, all the world's harvested biomass in 2000 had a gross energy content of about 230 EJ, including all harvested crops, crop residues, wood, and forages consumed by livestock (Chum et al., 2011; Haberl et al., 2012, 2007). These bioenergy estimates are therefore claiming that bioenergy is both low or no carbon and sustainable at levels that would double or triple total human plant harvest.
- Two, land use changes necessary to supply current biomass harvests (and its 230 EJ of energy) have contributed around one third of the world's cumulative CO_2 emissions since 1750 (Le Quéré et al., 2016). Nearly all strategies for stabilizing the climate at acceptable temperatures assume a rapid phase out of deforestation, and many assume increases in forest cover by 2050 (IPCC, 2014), in effect providing no room for additional depletion of land-based carbon stocks.
- Three, virtually all analyses project increases in demand for crops, milk, and meat on the order of 60–100%, plus increases in urban areas, and in the demand for wood products (Searchinger et al., 2013; Valin et al., 2014). Because of these projected increases in food demand, even with little or no increase in bioenergy, the vast majority of models estimate expansion of agricultural land by 2050, including several by more than half a billion hectares (Bajželj et al., 2014; Schmitz et al., 2014; Tilman and Clark, 2014).

Given this land use competition, as Bajželj et al. (2014) wrote pithily, "unless food demand patterns change significantly, there seems to be little spare land for bioenergy developments without a reduction of food availability" or, we add, without adverse effects on climate from

☆ *This article is part of a Virtual Special Issue entitled 'Scaling Up Biofuels? A Critical Look at Expectations, Performance and Governance'.*

* Corresponding author.
E-mail address: tsearchi@princeton.edu (T.D. Searchinger).

http://dx.doi.org/10.1016/j.enpol.2017.08.016
Received 23 December 2016; Received in revised form 2 August 2017; Accepted 4 August 2017

losses of terrestrial carbon. What then explains the estimates of large, low carbon, bioenergy potential from dedicated uses of land?

This paper seeks to explain these different viewpoints by exploring where and how the optimistic bioenergy estimates find the land or biomass for bioenergy and their claimed sources of greenhouse gas (GHG) benefits. We start by exploring the basic principles of biomass accounting and why biomass is not inherently carbon neutral. The benefit of bioenergy from dedicated use of land is the reduced emissions of fossil fuels, but the cost is not using that land to produce other plant outputs, including food and carbon storage. Proper accounting must examine net effects. Using basic opportunity cost calculations, we show why bioenergy even under highly favorable assumptions is unlikely to produce net climate benefits.

With this background, we explore the estimates of large bioenergy potential or GHG benefits from biophysical mapping, and economic models and show how they count the benefits of using land or biomass for bioenergy but not the costs. In effect, they double-count land or biomass as available for bioenergy even as the analyses assume they also continue to serve existing uses. Some integrated assessment models (IAMs) do not double-count in the same way, but we find that their bioenergy benefits are contingent on a variety of optimistic and uncertain assumptions. They provide not plausible bioenergy estimates, but idealized thought experiments if governments took many implausible actions to maximize global land use outputs.

2. Proper accounting of biomass

2.1. In general

Burning biomass releases carbon, and must release at least some more carbon than burning fossil fuels because of the lower energy per gram of carbon in biomass (IPCC, 2006). Regardless, typical lifecycle and other GHG analyses of bioenergy (Argonne National Laboratory, 2016), start with the assumption that biomass itself is an inherently "carbon neutral" fuel (Searchinger et al., 2009, 2015a). These analyses will typically count the emissions from trace greenhouse gases (N_2O and CH_4) and from fossil fuels used to produce and use biomass, but not the carbon from the biomass itself. The typical rationale is that biomass starts with plant growth, which absorbs carbon, and burning biomass only returns the carbon to the air while burning fossil fuels adds carbon to the air from underground.

This view makes a baseline error by getting the non-bioenergy counterfactual wrong. Viewed physically, the argument is that carbon absorbed by plant growth *offsets* the carbon released by burning biomass. The error: land usually grows plants regardless of whether those plants are used for energy. These plants are already withdrawing carbon from the air. Like any other offset, an offset by plant growth can only exist if and to the extent the plant growth is "additional" to the growth that would occur anyway. Counting existing plant growth as an offset counts the same carbon twice.

Moreover, just replacing plants with modest biomass yields on one hectare, such as lettuce, with plants that produce high biomass, such as trees, does not result in additional carbon uptake globally if people replace the low biomass plants somewhere else. Bioenergy can only reduce GHGs through plant growth if total plant growth increases globally while also factoring in any releases of stored carbon.

Bioenergy can also reduce carbon in the atmosphere if it reduces another source, so there is no net increase in emissions to the air. If residues were going to burn or decompose, using them for bioenergy reduces the emissions from the field, offsetting the emissions from burning them for energy in the car or power plant. Yet because even many residues and wastes are used rather than burned, if only to maintain soil carbon, their opportunity costs must also be counted (ICF International, 2015; Liska et al., 2014; Searle et al., 2017). Less attractively, if bioenergy reduces consumption of food products, it can also reduce emissions from human respiration.

To truly understand what analyses of large, low carbon bioenergy potential are predicting, it is therefore best to determine if, where and how each analysis projects offsets from increased plant growth or reduced oxidation.

2.2. Neither renewable nor sustainable plant harvest makes biomass carbon free

Plant growth not only absorbs carbon but is renewable, which some claim makes biomass carbon free so long as plants are allowed to regrow. The thinking is something like the following: "If the world uses plants for energy and the plants grow again, doing so cannot cost the world any carbon."

The analogy of a monthly paycheck illustrates the error in this thinking. Like annual plant growth, a paycheck is renewable in that a new check should come every month. But just because the money is "renewable" does not mean it is free to divert it to alternative uses. People cannot spend their paycheck on something new like more leisure travel or energy without sacrificing something they are already buying, like food and rent, or without adding less to their savings. To afford more leisure or energy, people either need a bigger paycheck or they must cut some source of waste.

Analogously, people use annual plant growth and the carbon it absorbs for food and forest products. Much plant growth goes to replenish or add to the carbon stored in vegetation and soils. The cost of using that plant growth for energy is not using it for these other purposes. To be richer in carbon, one cannot merely divert plants from one use to another; one needs more plant growth or elimination of some plant waste.

Accordingly, assuring that biomass production is sustainable does not make it carbon-free. Although vague, the term "sustainable" typically refers to maintaining long-term productivity, i.e., keeping something renewable. If renewable is not carbon free, neither is "sustainable."

In a strong sense in the forest context, sustainable might refer to harvest levels that maintain existing carbon stocks by only harvesting the annual, incremental growth of a forest. But the world's forests are accumulating around one gigaton of carbon on a net basis, which helps to hold down climate change (Pan et al., 2011). (A significant part of this gain is due to higher carbon dioxide itself and is already factored into climate projections as a mitigating feedback effect.) Ton for ton, burning up this biomass reduces this carbon sink and adds carbon to the air just as much as any other emission source.

2.3. IPCC national guidelines do not treat biomass as carbon free

Under the accounting guidelines for United Nations Framework Convention on Climate Change (UNFCCC), countries report their national emissions from using energy in one sector and from cutting down trees or making other land use changes in another sector (IPCC, 2006). If trees are cut down or land use change occurs to cultivate biomass for energy, the carbon released during the process is therefore counted. But the guidance recognizes that this approach has the potential to count emissions from bioenergy twice. Once the carbon in a tree is counted in the land use account, the guidelines provide that it should therefore not be counted again when burned in the energy sector even though its actual emissions occur there.

These features of the UNFCCC system work when used solely as a means of counting *global* emissions because (a) emissions from energy and land use are counted with equivalent significance, and (b) the system applies worldwide. If the United States cuts down trees and uses them to replace coal in power plants, it reports fewer emissions from coal but more from land use change. If Europe burns trees cut in the U.S., their emissions are still captured globally through the U.S. land use sector. If the United States diverts crops to biofuels, and the crops are replaced by converting land in Latin America, those land use change