DISCUSSION PAPER

April 2013 ■ RFF DP 13-11

Comparative Life Cycle Assessments: Carbon Neutrality and Wood Biomass Energy

Roger A. Sedjo

1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

RESOURCES FOR THE FUTURE

Comparative Life Cycle Assessments: Carbon Neutrality and Wood Biomass Energy

Roger A. Sedjo

Abstract

Biomass energy is expected to play a major role in the substitution of renewable energy sources for fossil fuels over the next several decades. The US Energy Information Administration (EIA 2012) forecasts increases in the share of biomass in US energy production from 8 percent in 2009 to 15 percent by 2035. The general view has been that carbon emitted into the atmosphere from biological materials is carbon neutral—part of a closed loop whereby plant regrowth simply recaptures the carbon emissions associated with the energy produced. Recently this view has been challenged, and the US Environmental Protection Agency (EPA) is considering regulations to be applied to biomass energy carbon emissions. A basic approach for analyses of environmental impacts has been the use of life cycle assessment (LCA), a methodology for assessing and measuring the environmental impact of a product over its lifetime—from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. However, LCA approaches vary, and the results of alternative methodologies often differ (Helin et al. 2012). This study investigates and compares the implications of these alternative approaches for emissions from wood biomass energy, the carbon footprint, and also highlights the differences in LCA environmental impacts.

Key Words: life cycle assessment, carbon neutrality, biomass, bioenergy, carbon dioxide, energy, rational expectations

JEL Classification Numbers: Q2, Q23, Q4, Q54

Contents

Comparative Life Cycle Assessments: Carbon Neutrality and Wood Biomass Energy

Roger A. Sedjo*

Introduction

Biomass energy is expected to play a major role in the substitution of renewable energy sources for fossil fuels over the next several decades. The U.S. Energy Information Administration (EIA 2012) forecasts increases in the share of biomass in U.S. energy production from 8 percent in 2009 to 15 percent by 2035. Although biogenic materials (wood, grasses, and plants, for example) do release carbon when combusted for energy, the general view has been that carbon emitted into the atmosphere from biological materials is carbon neutral—part of a closed loop whereby subsequent plant regrowth simply recaptures the carbon emissions associated with the energy produced.

This view has generally looked for support to the Intergovernmental Panel for Climate Chance (IPCC 2006) assessment. Although the IPCC never made any assumptions about neutrality or trends in carbon stocks, under the IPCC reporting rules the impacts of biomass energy would not be reported in the energy sector but would be reported in the land use change and forestry sector (LULUC). Hence, biomass energy could be viewed as carbon neutral since emissions would eventually be sequestered in future biological growth. In a steady state biological system (like the classic regulated forest), gross emissions would equal gross sequestration, thus net emissions would be zero. However, the IPCC includes caveats related to forest regeneration conditions and, specifically, this approach assumes that biomass stocks for the entity in question are at a long-term steady state.

Recently, this view has been challenged, and a dispute has ensued over the general carbon neutrality of biomass energy and the nature of any regulations that should be applied. Two noteworthy letters have been sent to Congress by eminent scientists examining the merits—or demerits—of biofuels in the climate debate. The first, from 90 scientists (dated May 17th, 2010) questioned the treatment of all biomass energy as carbon neutral, arguing that such treatment could undermine legislative emission-reduction goals. They stated that the

* Sedjo is a senior fellow and director of the Forest Economics and Policy Program at Resources for the Future, sedjo@rff.org. The author would like to thank Reid Miner for his many useful suggestions.

"replacement of fossil fuels with bioenergy does not directly stop carbon dioxide emissions from tailpipes or smokestacks." Thus, biomass energy—fuels derived from wood or other plant material—produces emissions and therefore is unlike other renewables, such as wind or solar. Also, they noted that time dimension is essentially ignored, so although net emissions may be zero over long time periods, they often will not be zero in shorter time periods. Additionally, this first letter stated that the biomass stock need not necessarily return to the earlier level, through regional deforestation, for example. Finally, they noted that biomass releases more carbon per energy unit than do most fossil fuels, although regrowth could offset this.

The second letter, by 110 forest scientists (dated July 20, 2010) expressed concern over equating biogenic carbon emission with fossil fuel emissions, such as contemplated in the EPA Tailoring Rule. They also noted, correctly, that carbon dioxide released from the combustion of wood biomass is part of the global cycle of biogenic carbon and "does not increase the amount of carbon in circulation," as would fossil fuel emissions (for a discussion and references see Sedjo 2011).

The regulatory question has become, under what conditions and to what extent should emissions of forest biomass energy feedstocks be treated like a fossil fuel, in that the carbon emissions be viewed as irreversible and regulated as such? Alternatively, are other regulatory treatments appropriate? And to what extent might a categorical exclusion from regulation be applied since most of the emissions are ultimately recaptured in subsequent biomass growth (EPA 2011)? LCA can inform the development of regulations to help identify any potential unintended consequences.

The purpose of this study is to examine recent approaches to applying LCA to forest wood as a feedstock for bioenergy, noting how the different underlying methodologies have generated different results, which has in turn contributed to the confusion and lack of clarity for regulation. This study demonstrates how the results may hinge on the particular LCA approach used in the assumptions surrounding the analysis. Hence, extreme caution should be used when applying the results of any particular LCA.

Background and Concepts

As noted above, until recently, the conventional wisdom was that the use of wood energy as a substitute for fossil fuels would reduce net carbon emissions since the wood biomass would substitute for fossil fuels, and wood, being a renewable resource, would recapture the emitted carbon as the forest regrows. Essentially, the carbon emitted by biomass energy would be recycled back into the forest. The assumption was that forest stock changes due to wood bioenergy would remain unchanged or increase (IPCC 2006).

Some analysts, however, have suggested that the simple regeneration assumption may not be adequate. After all, not all forests experience regeneration. A concern is that the use of wood biofuels will decrease the forest stock at a rate exceeding regrowth and thus reduce the net carbon captured in the forest, thereby offsetting some or all of the gains to the decrease of fossil fuel use. Furthermore, as noted by Cherubini et al. (2011), although a sustainable forest may be carbon neutral, that is forest stocks remain constant over a rotation despite their use as bioenergy, there would be periods of volume decline followed by periods of volume growth (see WBCSD 2012). Thus, although the long-term net change in the amount of carbon captured in the forest may be zero, in the shorter term the initial large emissions may not be fully offset by regrowth, and so using wood biomass energy can generate substantial near-term increases in atmospheric carbon.

By contrast, a regulated forest, a concept common in forestry (Davis and Johnson 1986), would be both sustainable and carbon neutral across time periods. In a regulated forest, the volume harvest per period (typically one year) is just equal to the new growth of the forest system for that same period. Such a forest retains a constant volume of wood over time periods as volume harvest just equals net growth per period. In essence, the forester is harvesting the net growth but leaving forest stock constant. Foresters have long noted that such a forest retains a constant volume of wood over time. A clear implication of this is that the forest also maintains a constant volume of carbon over time and that no net carbon is being released to the atmosphere, even if all the harvested wood is used for bioenergy. A sustainable forest would recycle biomass energy emissions back into the forest through regrowth, although there may be period of net emissions followed by periods of net sequestration. Indeed, a forester's regulated forest, where the annual harvest equals the annual net growth, would find no net emissions and thus carbon would be neutral in both the short or long term.

Whether or not, as an empirical question, individual forests are managed as regulated forests, it should be noted that in many countries of the world, including most of Europe, the United States, and China, the net volume of forest biomass has been increasing in recent decades. So whatever the condition of a particular forest in these countries, the aggregate forest systems of many of these countries have been more than sustainable in recent decades, and the aggregate forest carbon stocks in the forests of these countries have been increasing.

What Is Life Cycle Assessment?

A basic approach for analyses has been the use of Life Cycle Assessment (LCA). LCA is a methodology for assessing and measuring the environmental impact of a product over its lifetime (Rebitzer et al. 2004; Finnveden et al. 2009). An LCA is a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling). LCA procedures are part of the ISO 14000 environmental management standards: in ISO 14040:2006 and 14044:2006. (http://www.iso14000-iso14001-environmental-management.com/)

An LCA is typically initiated by defining the goal and scope of the study. This is followed by a life cycle inventory: an inventory of flows from and to nature for a product system. The major purpose of the analysis is to quantify the inputs and outputs and then determine how the product affects the environment. The approach can also be applied to a particular environmental impact, such as carbon emissions, throughout the bioenergy life cycle. This study abstracts from the multiple flow focus, limiting its concentration to carbon dioxide releases to the atmosphere and from wood biomass energy production and sequestration from the atmosphere.

As applied to carbon emissions, Helin et al. (2012) have noted that "Many biomass GHG accounting methods have been developed resulting in notably different conclusions," and they undertake a study that discusses the various approaches (e.g., Lippke et al. 2009; Manomet 2010; Malmsheimer et al. 2011). Among other things, Helin et al. suggest that the timing of releases and re-sequestration is important, and they also note, as does the WBCSD (2012), the criticality of the definition of spatial and temporal system boundaries. Furthermore, Helin et al. note the development of different "LCA modes or types." As developed by Currant et al. (2005), an "attributional" LCA (ALCA) can be defined as a method that aims "to describe the environmentally relevant physical flows of a past, current or potential future product system." This type of assessment is called "attributional" because it characterrises the attributes of the system being study as they exist, independend of other systems. However, Currant et al. note that a "consequential" LCA (CLCA) can be defined as a method that aims "to describe how environmentally relevant physical flows would have been or would be changed in response to possible decisions that would have been or would be made" (in Helin et al 2012 p 2). It is "consequential " in that it attempts to charactrize the consequences of using the product on other product systems. Thus, the ALCA attempts to describe the product system more or less as it is, whereas the CLCA asks, "What if?" Or, restated, the ALCA treats most other factors as constant, *ceteris parabis*, while the CLCA recognizes that changes in the product system could result in management and market responses to its use. These anticipated responses are incorporated into the dynamic CLCA. This paper undertakes an investigation of the application and implications of the two extremes, and an intervening intermediate approach for wood biomass energy is undertaken below.

Wood for Bioenergy

The use of wood bioenergy is a two-way street that can affect supply as well as demand. Long-term forest management models recognize that harvest levels and management investments are related (Sohngen et al. 1999; Adams et al. 1996). Consider now the models used by Sohngen et al. and Adams et al. At any point in time the forest management decision includes a number of different sites in different stages of growth; for example, some are mature, others are mid-aged, and still other sites have just been harvested and are ready for replanting. Additionally, some sites may be suitable for conversion from cropping or pasture to forest under proper incentives. In these analyses, management and investments decision are driven importantly by anticipated future markets. This approach is known as forward looking or involving rational expectations (Muth 1961; Takayama and Judge 1971).

Given an expectation of a significant increase in the demand for wood biogenic energy, such as forecast by the EIA, it is clear that a forward-looking approach of bioenergy harvests from forests would anticipate a resulting reduced store of forest stock and carbon and release carbon into the atmosphere, in the absence of any offsetting activities. It is also clear, however, that an anticipation of higher levels of future demand for wood biomass will encourage increased investments in forests for biomass energy. Indeed, to the extent that these investments (think forest expansions, new plantings, improved faster-growing seedlings, intensive management to increase yields) need be undertaken in anticipation of future demand not yet realized, forest expansion could precede harvests, and carbon will be newly captured, thereby preceding its future release. Because these investments are trigged by anticipated increases in future demand, the expansion of forests and harvests is additional to what would have been the "business-as-usual forest."

Many such assessments of the relationship between the carbon sequestered in the forest and net carbon emissions associated with wood bioenergy take an accounting view of a static forest stand, that is, static in their treatment of supply and demand effects, (Manomet 2010; Puettmann and Wilson 2005). Even when making an assessment over time, each stand and each period is treated more or less independently of other stands and periods. For example, in studying the carbon neutrality issue in wood biomass production, the Manomet report's authors analyzed an individual mature forest stand and independent exogenous harvest decisions.

However, recent assessments have recognized that supply is responsive to demand and that forestry is a dynamic system in which management reacts to market changes on a broad scale involving multiple stands and multiple forests. These systems have general equilibrium characteristics, and changes in demand in one forest will be transmitted throughout the multi-forest system. A decision to harvest in one forest in a particular time period involves related forest management decisions for other stands, other forests, and other time periods. If future demand is expected to increase, forest managers behave differently than if they expect future demand to be constant or lower. Higher expected future prices encourage forest expansion, with more active forestland management, such as tree planting and silviculture. Indeed, if near-term price trends are expected to rise, current harvest can actually decline as managers "conserve" the wood for future sale in a higher-price period. This phenomenon is not limited to the behavior of one forest manager in one forest but rather will be transmitted via market signals (prices) throughout the system to all forest managers. In a world of scarce energy with rising prices, where biomass is beginning to play a substantive role, future wood prices can be expected to rise. Indeed, some industrial wood mills anticipate having to compete with the biomass feedstock market, and concerns about rising wood prices may well be valid (Sedjo and Sohngen 2013).

Comparative Analysis

This section compares the application of an LCA-type approach in three studies ranging from most to least constrained. These are the Manomet study (Walker et al. 2010); the Canadian mature forest study (McKechnie et al. 2011); and the conceptual Timber Supply Model (TSM) analysis by Sedjo and Tian (2012). The Manomet study, the most constrained, uses an LCA to examine the net level of GHG emissions from the use of wood from a mature forest site over a 100-year time period. This analysis involves a single harvest on a single plot followed by regeneration. However, no other adjustments are allowed, and there is no change in expectations of future markets or prices.

The Canadian study, an intermediate case, examines the carbon effects of periodic harvests from a changing subset of the various plots on a large mature forest. This forest has large but fixed land area and boundaries. Having multiple plots allows for an examination of the LCA carbon implications through time where harvests and new forest growth are occurring in the same time period. A fixed annual harvest level is set with the individual annual harvests occurring on various mature plots. The harvested plots are assumed to regenerate at historic rates. As more plots are harvested, the net cumulative growth on these plots gradually increases as the forest system asymptotically approaches a steady state. However, the steady state is only achieved beyond the end of the 100-year analysis.

Finally, the TSM, the least constrained approach, uses a well-known rational expectations multi-plot timber projections model to examine the LCA effects of an anticipated increase in demand for wood biomass energy. This system allows forest investments and land use to change depending upon current and anticipation market conditions. Also, the system is not constrained by land boundaries other than the stipulation that the land must provide better economic returns in forest than in alternative uses. To do this the land rents increase as more land is drawn into forestry, reflecting the higher opportunity costs. (This approach could constrain forest land to the initial boundaries but still allow for forest stock expansion due to more intensive forest management investments.) This analysis allows management to respond to market changes—for example, with new forest investments and more intensive management—and is (generally) not constrained by non-economic land constraints. It can be argued that the entire U.S. forest estate is best represented by a multi-plot approach that in turn represents the aggregate forestlands of the country, the management of which is driven by market signals.

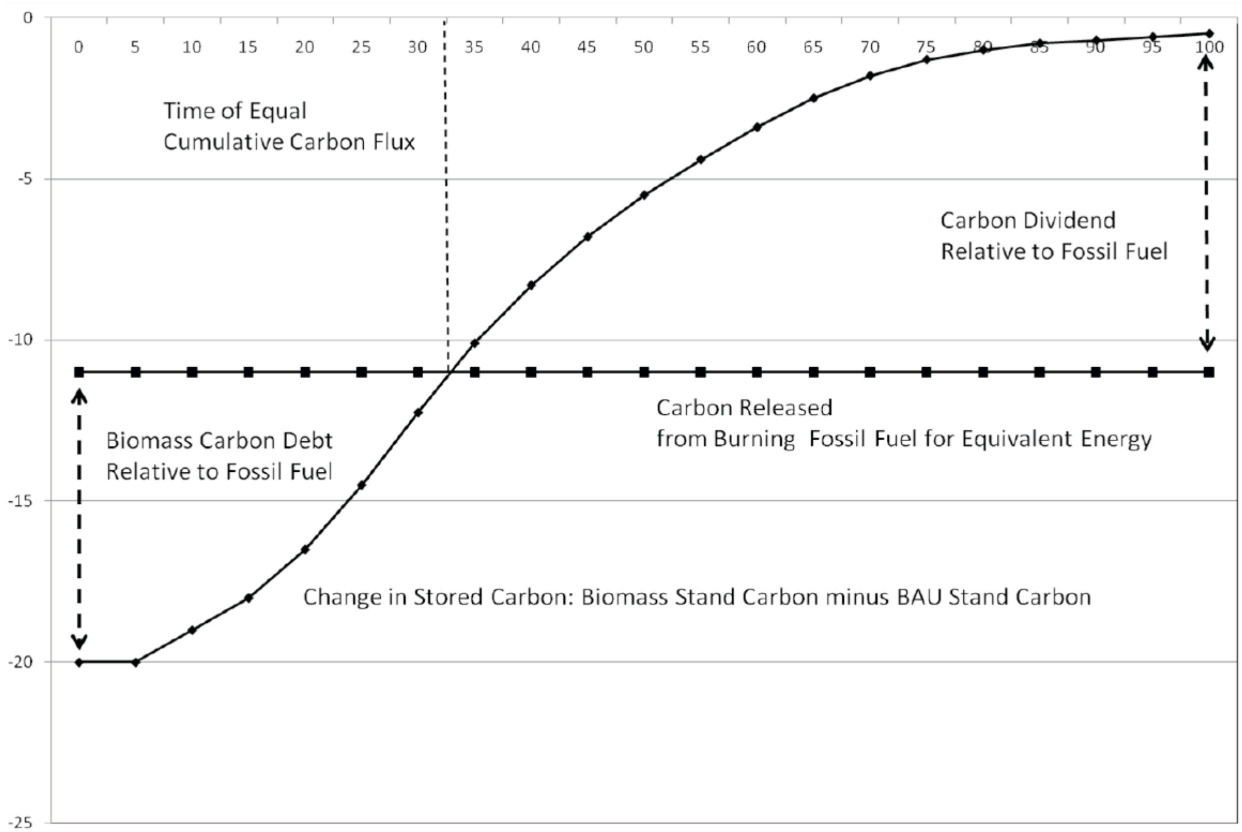
Life Cycle Assessments of the Cases

Manomet Study

The Manomet study, released by Center for Conservation Sciences (2010), was commissioned by the State of Massachusetts to help inform the legislature as to the feasibility of substituting wood biomass for coal in some of its electrical power generation. A concern of the legislature was meeting near-term emission reduction targets, which was subsequently viewed as problematic in light of the long-term nature of the carbon benefits identified.

The study's LCA examines the effect on atmospheric carbon of a one-time wood harvest, with the wood being substituted for fossil fuels for energy production. The study focuses on the emissions of the wood from that site and on the regrowth that occurs on that site. In that context, it is assumed that the decision to use harvested wood from that site has no effect on management decisions on other forests or other sites. Thus the study has the implicit assumption of *certeris paribus*; that is, other things being held constant. The approach traces the emissions associated with the wood substitution and the GHGs sequestered (Fig 1). The approach inventories the one-time carbon release and subsequent sequestration over the extended period (roughly 100 years), during which the regenerated forest replaces the original mature forest. The biomass carbon debt of the first 35 years reflects the fact that wood emits a larger volume of GHGs than fossil fuels for a given amount of energy production. However, as the harvested area is replaced by forest regrowth, the deficit is gradually offset as subsequent regrowth sequesters the earlier emissions, resulting in no net forest emissions over the complete cycle.

Figure 1. Manomet Study



Source: Manomet 2010.

The schematic above represents the incremental carbon storage over time of a stand harvested for biomass energy wood relative to a typically harvested stand (BAU). The site experiences an initial carbon debt (9 tonnes) that is shown as the difference between the total carbon harvested for biomass (20 tonnes) and the carbon released by fossil fuel burning (11 tonnes) that produces an equivalent amount of energy. The carbon dividend is defined in the graph as the portion of the fossil fuel emissions (11 tonnes) that are offset by forest growth at a particular point in time. In the example, this is after the 9-tonne biomass carbon debt is recovered by forest growth (year 32) (Manomet 2010).

The Manomet study concludes that a carbon debt will be incurred for the first 32 years for this particular forest, after which the continuing regrowth will sequester net carbon over what would be the case in the absence of the substitution of the biomass for the previously used fossil fuel. After this time:

> GHG levels fall below what they would have been had an equivalent amount of energy been generated from fossil fuels. This is the point at which the benefits of burning biomass begin to accrue, rising over time as the forest sequesters greater amounts of carbon relative to the typical harvest (Manomet 2010).

Note here that an important issue is the carbon debt, which persists in this analysis for 32 years. Indeed, this type of analysis discouraged the use of wood for bioenergy since many of the carbon targets are relatively near-term, e.g., a net carbon reduction by 2020.

Observe that the delayed benefits of the use of wood to substitute for fossil fuels suggested that short-term GHG emissions targets would not be assisted by the use of bioenergy. This finding gave the Massachusetts legislature pause regarding whether to move ahead with bioenergy.

Canadian Forest Study

This study (McKechnie et al. 2011) involves a large mature natural forest (fixed at 5.3 million ha) that relies on natural regeneration for regrowth. The forest land area and market conditions are assumed to be fixed. At the inception of the analysis, the forest begins to be harvested at a constant annual rate that is sustainable in the long term. However, it requires over 100 years to convert the forest to the steady state—that is, where growth in the harvested areas equals the continuing harvest in the various plots. The study examines a number of alternative scenarios in which the wood can be used for a variety of purposes, for example, including consideration of long-lived forest products sequester carbon well beyond the life of the tree. Other alternatives examined in the study include pellets produced from wood residues, pellets from standing trees, ethanol from residues and from standing trees. In most scenarios involving the substitution of bioenergy for fossil fuels, total emissions are reduced in these analyses. Total emissions tend to rise in the early periods and generally decline thereafter as the increased harvest areas experience regrowth and begin to sequester carbon. The new steady state forest has less carbon in it than did the initial mature forest, but for most scenarios examined, the net effect was to decrease total carbon emissions within the 100-year period or less—in some cases far less. This analysis demonstrates that the type of energy use to which the biomass is put can be important to the timing of sequestration and the net benefits of using biomass. In many respects, this study is simply the application of a Manomet approach to a larger multi-plot forest with continuous periodic harvests. Since the harvests continue indefinitely, however, the final steady state forest stock will be smaller than the original mature forest.

TSM study

The Sedjo/Tian (2012) analysis, uses a variant of a well-known dynamic optimization forest management model (Daigneault et al. 2012; Sohngen et al. 1999; Sedjo and Sohngen 2013) to examine the effect of changing wood biomass demand on the existing forest and the amount of carbon captured by the forest system. The approach, which uses a continuous time optimal control model, is presented below. The model maximizes the net present value of net surplus in wood biomass markets. Net surplus is defined as the area between the biomass demand curve and the land rent cost, often simply characterized as profit. Modifying Sohngen et al. (1999), the social planner's problem is thus:

$$\max_{\{H(t),G(t)\}} \int_0^{\infty} e^{-rt} \left\{ \int_0^{Q(t)} D\left(Q\big(H(t), V(a)\big)\right) dQ - R(t)X(t) \right\} dt \quad (1)$$

s. t

$$\hat{X} = -H(t) + G(t) \quad (2)$$

$$H(t) \geq 0; G(t) \geq 0; X(0) \text{ is given}$$

D(·) is a downward sloping demand function given the wood biomass quantity per period. Q(·) is the total quantity harvested generated by the demand function. H(·) is the hectares harvested, G(·) the hectare planted, and V(a) is the wood biomass yield function, where a is the age of plants harvested. R(·) represents land rent or the opportunity cost of maintaining land as forest rather than allowing it for alternatives uses. X(·) is the forest land hectares. The variable r is the interest rate that should reflect the risk with carbon uptake service (e.g., fire risk, slower than expected tree growth, etc.). The state variable here is X(t). The choice variables are H(t) and G(t). The state variable will vary over time according to Equation (2), where $\hat{X}$ is the increased hectares of forests between current period and the next period.

We further modify the earlier model where forest land is fixed, to allow forested land and wood biomass to expand or contract by planting and harvest (Equation 2). So there is the possibility that some harvested land may not be replanted, thereby falling out of forest, and also the possibility that additional land will be converted to forest.

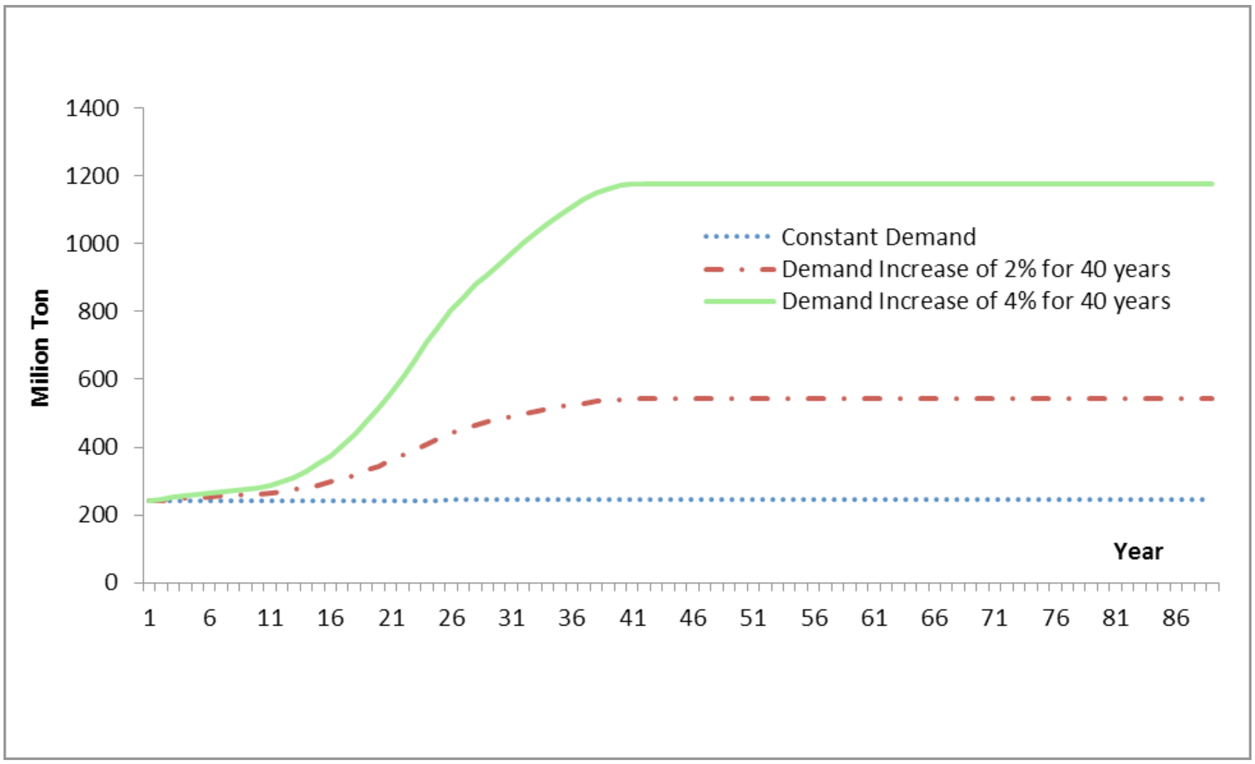
In the dynamic forest management model, management activities over time respond to current and anticipated market conditions that maximize financial returns to the forest, under alternative scenarios with different rates of demand growth, elasticities of forestland supply, and growth-and-yield functions. This approach recognizes that increased, expected, or actual demand will influence both harvest levels but also investments in new forests production via management in the direction of increased investments in forests, such as through tree planting and silvicultural activities. The approach examines the intertemporal path of forest carbon stocks and changes in this path due to the increased use of wood for bioenergy and the induced increase in forest investments and management. The approach uses a general stylized forest sector model to examine the effects of an increase in the use of wood biomass energy on the amount of carbon captured in the forest over time under several hypothetical conditions.

Sedjo-Tian (2012) apply a CLCA approach to a forward-looking forest management projections model—a rational expectations approach (e.g., see Sohngen et al. 1999; Adams, et al. 1996). We focus on situations where the market for biomass energy is expected to increase substantially, primarily over a 40-year period, although we also look at situations of declining biomass energy demands applied to wood biomass for energy. This study utilizes alternative scenarios with respect to future increases in demand for wood for biofuel, and associated higher prices are anticipated. Responding to higher demand and prices, new forest investments are made consistent with those anticipations. In the real world, these investments could take many forms, such as improved genetic tree stock, fertilization, and modified harvesting techniques. In the model, the investment takes the form of expansion of forest area; specifically, more land is brought into forestry at a rental price for land, which is rising as more land is brought into forest.

The implications of this approach on forests and forest carbon are presented in the scenarios of Figures 2–5. This analysis suggests that the market will respond to an anticipation of increased future demand growth for biomass for energy by increasing investments in wood biomass for energy. Figure 2 hypothesizes three anticipated future price growth paths: no anticipated price changes; a 2 percent annual anticipated increase in prices over a 40 year period; and a 4 percent annual price increase over a 40-year period. Figure 3 shows the areas of forest associated with the alternative anticipated price rises; Figure 4 presents the harvest volume paths associated with each path; and Figure 5 projects the path of the volume of carbon captured in the various alternative forests. Similar graphs have been developed for the expectation of a decline in wood biomass energy prices, and they indicate declining paths for forest area, harvest volumes, and forest carbon volumes.

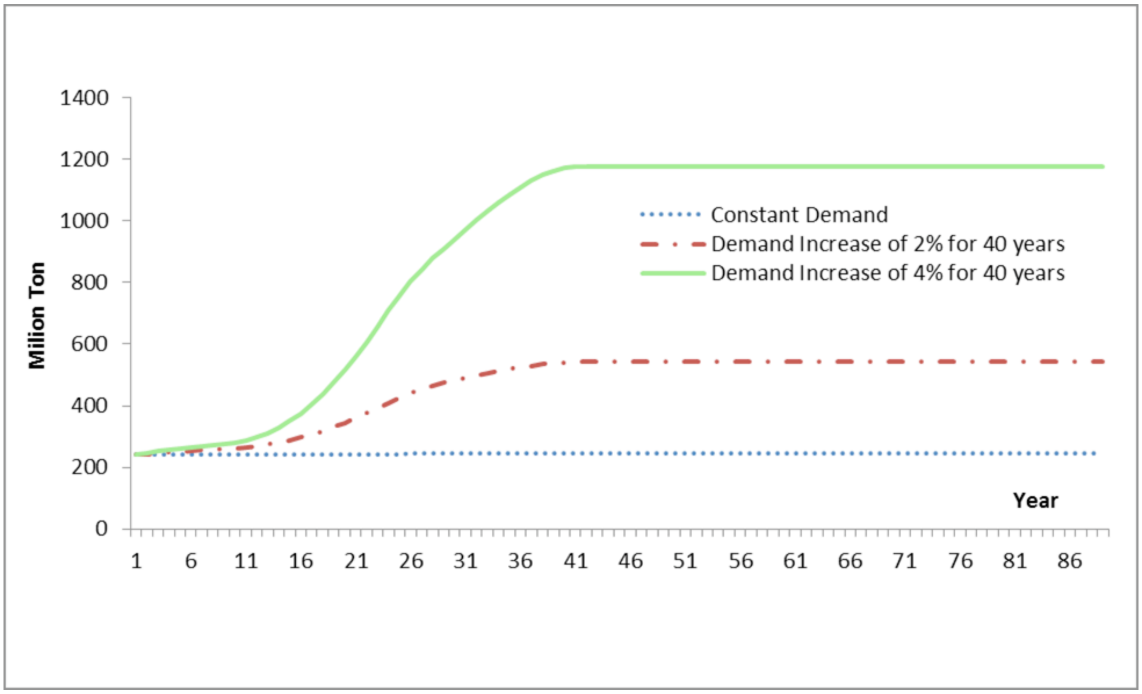
Although one need not accept the precise growth paths, one would expect that the anticipation of almost everyone—including, importantly, the U.S. EIA and the International Energy Agency—of an increased role for wood and biomass in energy would influence investment decisions in the wood industry. In short, this analysis suggests that anticipated large increases in wood biomass for energy over the next few decades would be expected to stimulate wood markets and encourage investment in forest and other biomass feedstock operations.

Figure 2. Anticipated Harvest Price Path



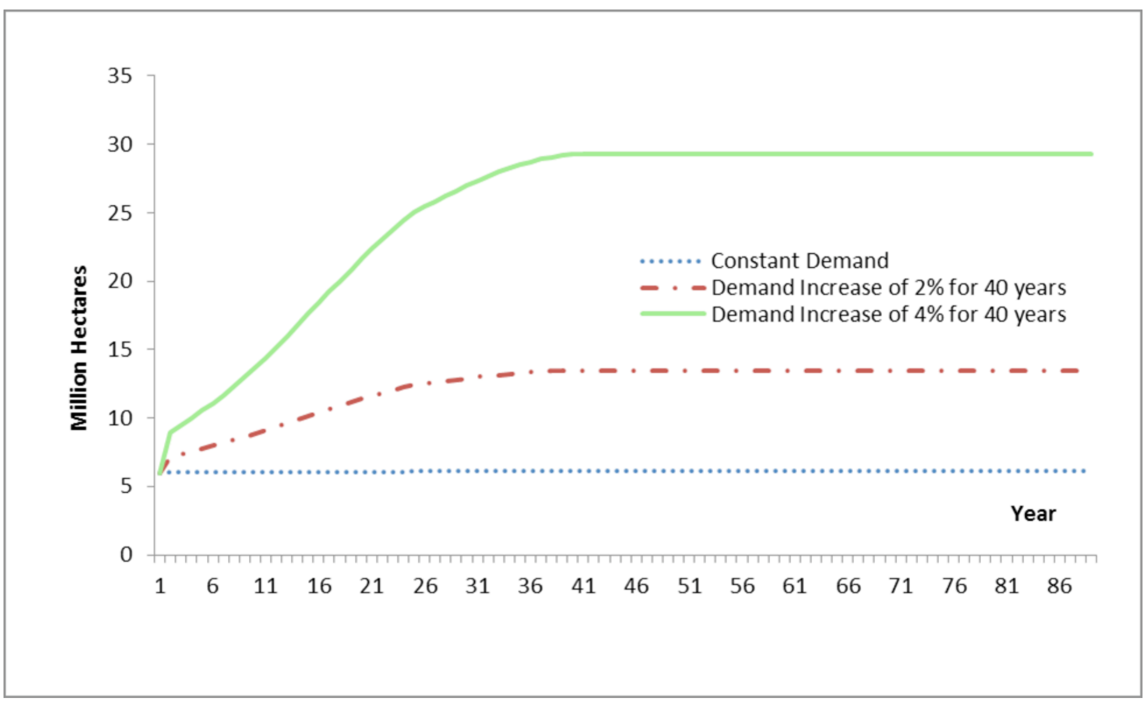
Source: Sedjo and Tian 2012.

Figure 3. Carbon Capture Path



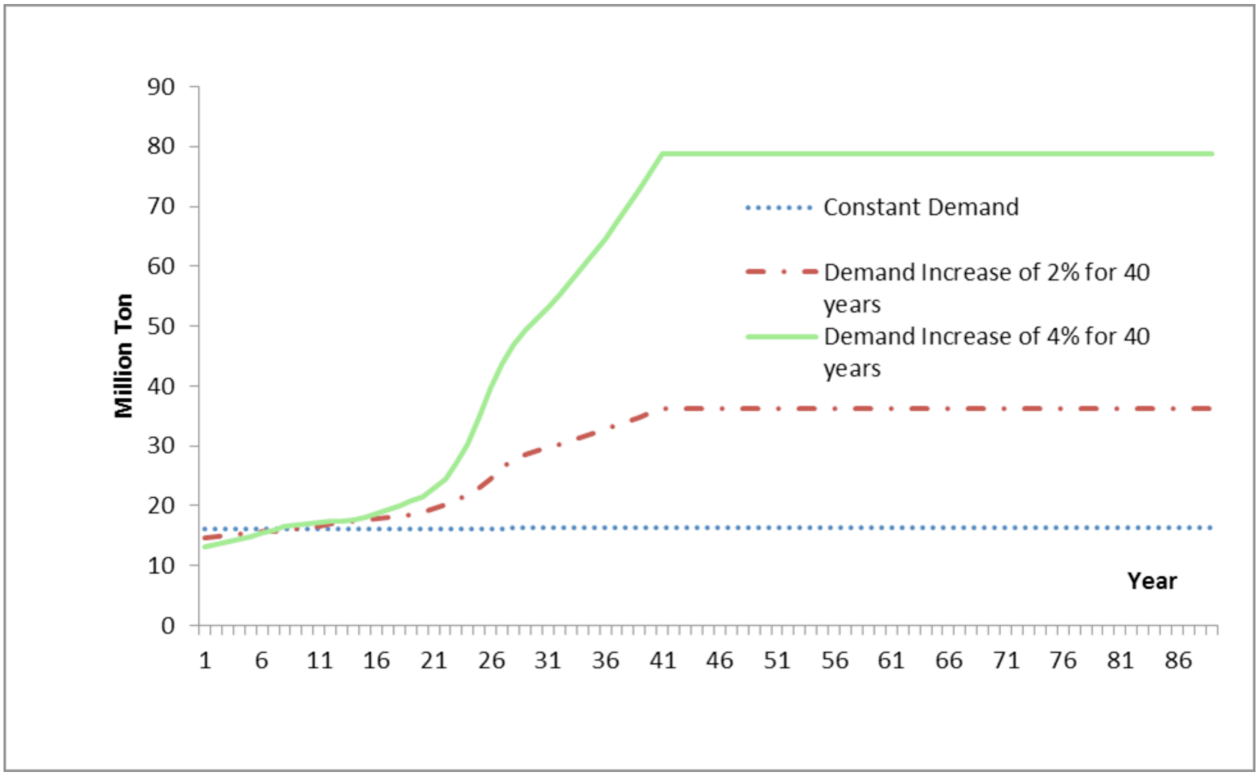
Source: Sedjo and Tian 2012.

Figure 4. Forest Area Path



Source: Sedjo and Tian 2012.

Figure 5. Harvest Volume Path



Source: Sedjo and Tian 2012.

Summary and Conclusions

Biomass, including wood, can substitute fossil fuel as an energy source through direct combustion of wood chips and pellets or via the conversion of biomass into biofuels such as ethanol and similar energy products. This paper examines the use of LCA to estimate the effects of forest harvests for biomass feedstock on GHG emissions. LCA is commonly used to assess the environmental implications of various products and activities, including the net effect on carbon and other GHG emissions. Important aspects in the application of LCA to emissions of wood biomass feedstock are the definition of boundaries, the treatment of time and consideration of market dynamics.

However, the literature suggests that there are a number of different LCA approaches and that these can generate very different findings (Helin 2012). Various methodologies have been used in the application of LCA generally, and more specifically to the estimate of GHG emissions from forest harvests used for bioenergy. This paper examines some of those methodological variations. At one end of the spectrum is an analysis with narrow, fixed boundaries that looks at a single product over its lifetime while assuming that other things, including markets, prices, and investments, are unchanged by the use of the product. At the other end of the spectrum is an LCA that incorporates changes in markets, prices, and investment levels directly attributable to the use of the emissions producing product. If the use of the product does not create effects on markets, prices, or investments, then the two extremes converge for given boundaries and time horizons. This paper examines three case studies in the literature ranging from the Manomet study—which uses the very narrow methodology with restricted boundaries (a single forest stand harvest at a single point in time) while assuming wood and energy markets (for example) are unaffected—to the TSM—which uses an unconstrained approach and anticipates that the consequences of widespread demand increases for wood for biomass energy will be sufficiently large so as to affect future markets, prices and investments, and forestland areas. An intermediate case study, the Canadian case, which treats markets as relatively fixed while allowing for numerous harvests over time and space within a fixed forest area, is also examined to highlight some of the methodological differences.

Although the different approaches were not applied to identical case conditions, it is clear that the results differ substantially and the differences are the results of using different LCA methodologies and the inherent differences in assumptions. Finallly, given sufficient time and assuming that complete regeneration replaces harvest, all three approaches will generate no net emissions for their respective forest since each becomes a fully regulated forest in which growth equals harvest for each of the three different time periods. Thus, the implication is that the use of wood biomass for energy will imply no net forest emissions to the atmosphere given adequate regeneration and sufficient time.

References

Adams, D., Alig, R., Callaway, J., Winnett, S. and McCarl, B. (1996). The Forest and Agricultural Sector Optimization Model (FASOM): Model Structure, Policy and Applications. Portland, OR: USDA Forest Service, Pacific Northwest Experiment Station.

Cherubini F, Peters GP, Berntsen T, Strømman AH, Hertwich E (2011) CO_2 emissions from biomass combustion for bioenergy: atmospheric decay and contribution to global warming. Global Change Biology Bioenergy, 3, 413–426.

Curran MA, Mann M, Norris G (2005) The international workshop on electricity data for life cycle inventories. Journal of Cleaner Production, 8, 853–862.

Daigneault, A., B. Sohngen and R. Sedjo. 2011. "Economic Approach to Assess the Forest Carbon Implications of Biomass Energy", Environmental Science and Technology. 2012, 46, 5664−5671.

Davis, L. and K. N. Johnson. (1986). Forest Management Third Edition, McGraw-Hill, Inc.

EPA (U.S. Environmental Protection Agency). 2012. "Air emissions: Non-hydroelectric renewable energy – Biomass." Website online at http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html; last accessed Feb.29, 2012.

EIA (U.S. Energy Information Administration). 2011. Annual Energy Review 2010. Office of Energy Statistics, U.S. Dept. of Energy, Washington, DC.

Finnveden G, Hauschild MZ, Ekvall T et al. (2009) Recent developments in life cycle assessment. Journal of Environmental Management, 1, 1–21.

HELIN, TUOMAS, LAURA SOKKA, SAMPO SOIMAKALLIO, KIM PINGOUD and TIINA PAJULA. 2012. "Approaches for Inclusion of Forest Carbon Cycle in Life Cycle Assessment – A Review," in Global Change Biology: Bioenergy, doi: 10.1111/gcbb. 12016.

IPCC (2006) Agriculture, Forestry and Other Land Use. Intergovernmental Panel on Climate Change, IPCC Guidelines for National Greenhouse Gas Inventories. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html (accessed 20 July 2012).

IPCC (2007a) Fourth Assessment Report (AR 4). Working Group I Report 'The Physical Science Basis'. Available at: http://www.ipcc.ch/ipccreports/ar4-wg1.htm (accessed 20 July 2012)

ISO 14040 (2006) Environmental Management. Life cycle Assessment. Principles and Framework. International Organization for Standardization, Geneva, Switzerland.

ISO 14044 (2006) Environmental Management. Life cycle Assessment. Requirements and Guidelines. International Organization for Standardization, Geneva, Switzerland.

ISO/DIS 14067 (2012) (Draft international standard). Carbon Footprint of Products – Requirements and Guidelines for Quantification and Communication. International Organization for Standardization, Geneva, Switzerland.

Rebitzer G, Ekvall T, Frischknecht R et al. (2004) Life cycle assessment part 1: framework, goal and scope definition, inventory analysis, and applications. Environment International, 30, 701–720.

Lippke, B. Oneil, E. Harrison, R., Skog, K., Gustavsson, L., Sathre, R. (2011) Life cycle impacts of forest management and wood utilization on carbon mitigation: knowns and unknowns, Carbon Management 2(3), 303-333.

Malmsheimer, R.W., J.S. Bowyer, J.S. Fried, E. Gee, R.L. Izlar, R.A. Miner, I.A. Munn, E. Oneil, and W.C. Stewart. 2011. Forest carbon stocks and flows. Section 2 in SAF Task Force Report: Managing forests because carbon matters: Integrating energy, products, and land management policy. Journal of Forestry 109(7S) (Oct./Nov. 2011 supplement): S14-S20.

Manomet (Manomet Center for Conservation Sciences). 2010. Massachusetts Biomass Sustainability and Carbon Policy Study: Report to the Commonwealth of Massachusetts Department of Energy Resources. Walker, T. (Ed.). Contributors: Cardellichio, P., Colnes, A., Gunn, J., Kittler, B., Perschel, R., Recchia, C., Saah, D., and Walker, T. Natural Capital Initiative Report NCI-2010-03. Brunswick, Maine.

McKechnie, J., S. Colombo, H. Chen, W. Mabee, and H.L. MacLean. 2011. Forest Biotechnology or Forest Carbon? Assessing Trade-Offs in Greenhouse Gas Mitigation with Wood-Based Fuels. Environ. Sci. Technol. 2011: 45, 789-795.

Muth, J.F. 1961. Rational expectations and the theory of price movements. Reprint, p. 3-23 in The new classical macroeconomics, vol. 1 (1992). International Library of Critical Writings in Economics, vol. 19. Elgar, Aldershot, U.K.

Pehnt, Martin (2006). "Dynamic life cycle assessment (LCA) of renewable energy technologies". Renewable Energy: an International Journal 31 (1): 55–71. doi:10.1016/j.renene.2005.03.002.

Puettmann, M.E., and Wilson, J.B. 2005. "Life-cycle analysis for wood products: cradle-to-gate LCI of residential wood building materials." Wood and Fiber Science 37, 18-29.

Sedjo R.A. (2011) "Carbon Neutrality and Bioenergy. A Zero-Sum Game?" RFF DP 11-15. Resources for the Future, Washington DC.

Sedjo, R.A. and B. Sohngen. 2013. "Wood as a Major Feedstock for Biofuel Production in the U.S.: Impacts on Forests and International T Journal of Sustainable Forestry, in Journal of Sustainable Forestry, 32:195-211, 2013.

Sedjo R.A., and X. Tian. 2012 "What Is the Carbon Footprint of Wood Biomass Energy?" by Roger Sedjo and Xiaohui Tian, Journal of Forestry, Volume 110(6): 304-311. 2012

Sedjo R.A., and X. Tian. 2012a. "An investigation of the effects of wood bioenergy on forest carbon stocks," Journal of Environmental Protection (JEP), September 2012 (Vol. 3 No. 9).

Sohngen, B., R. Mendelsohn, and R. Sedjo. 1999. Forest management, conservation, and global timber markets. American Journal of Agricultural Economics 81(1):1–13.

Takayama, T., and G.G. Judge. 1971. Spatial and temporal price and allocation models. North Holland Press, Amsterdam.

Walker T, Cardellichio P, Colnes A et al. (2010) Biomass Sustainability and Carbon Policy Study. National Capital Initiative at Manomet Report. Manomet Center for Conservation Studies, MA, USA.

World Business Council on Sustainable Development (WBCSD): forest solutions. 2012. "Issue Brief: Biomass Carbon Neutrality," Technical content developed by ncasi.