
ELSEVIER
January 2012 Volume 93 Number 1 ISSN 0301-4797
Journal of
Environmental
Management

Journal of Environmental Management 106 (2012) 1–7

Contents lists available at SciVerse ScienceDirect

Journal of Environmental Management

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

Forest-based biomass supply in Massachusetts: How much is there and how much is available

Marla Markowski-Lindsay [a,*], Paul Catanzaro [a], David Damery [a], David B. Kittredge [a], Brett J. Butler [b], Thomas Stevens [c]

[a] University of Massachusetts, Department of Environmental Conservation, 160 Holdsworth Way, Amherst, MA 01003, USA
[b] U.S. Forest Service – Northern Research Station, Family Forest Research Center, 160 Holdsworth Way, Amherst, MA 01003, USA
[c] University of Massachusetts, Department of Resource Economics, 216 Stockbridge Hall, Amherst, MA 01003, USA

ARTICLE INFO

Article history:
Received 25 May 2011
Received in revised form
20 March 2012
Accepted 26 March 2012
Available online xxx

Keywords:
Forest biomass supply
Owner attitudes
Bioenergy

ABSTRACT

Forest owners in Massachusetts (U.S.) live in a densely populated state and near forestland that is under pressure of development and characterized by small parcel size. Forest-based biomass harvesting in Massachusetts is a renewable energy topic generating a great deal of discussion among all constituents. To provide perspective on these discussions, our analysis asks how much forested land in Massachusetts could be available for biomass supply. This analysis considers the level of bioenergy production that could be maintained on an annual basis given the amount of woody biomass that is likely to be supplied from private- and state-owned Massachusetts forests, which comprises nearly 90% of the state's forests. Applying the most recent information on forest ownership and owner attitudes in Massachusetts, we estimate that between 80,000 and 369,000 dry tons/year of available wood-based biomass from forest management practices on private- and state-owned forests, or between 1.4 trillion and 6.2 trillion BTUs/year. These estimates represent between 0.09% and 0.42% of all Massachusetts residential, commercial and industrial annual consumption. These estimates are well below Kelty et al.'s (2008) estimate of 891,000 dry tons/year; the largest factors in this reduction are the reduced contribution of biomass due to social constraints and the amount of state land considered to be open to active management. Conversations regarding the use of biomass and its impacts on forests, as well as the development of biomass-related policy, should consider the supply of biomass that is likely available. While overall forest inventory estimates suggest one degree of availability, our research suggests that this needs to be tempered with the reality of ownership size and owner attitudes.

1. Introduction

The topic of forest-based biomass harvesting in Massachusetts has generated heated discussion among policymakers, the public, foresters, and private industry. Some in private industry want to utilize this regionally abundant resource to produce energy and electricity. Some segments of the public see this as an opportunity for greater energy independence and economic growth, while others oppose the use of biomass based on concern over its potential impacts to the health of the forests, air quality, carbon emissions, and other factors. Many foresters view biomass as an opportunity to improve markets for low-grade trees, improving silvicultural opportunities (Leonard and Kim, 2011). Policymakers find themselves in the middle of this debate, faced with differing opinions and information about the benefits and risks of using forest-based biomass for bioenergy. Massachusetts commissioned a report to analyze the carbon cycle implications of using logging residues and low-quality wood from actively managed forests for generating energy in the state (Manomet, 2010a). In the process of conducting this analysis, Manomet (2010a) estimates forest-based biomass supply from harvesting on public and private lands in Massachusetts, using a methodology based, in part, on historical practices, not direct elicitation of landowner preferences.

To provide perspective on these discussions and test a methodology for determining the availability of forest-based biomass, our analysis incorporates both the social and biophysical constraints to examine how much forested land in Massachusetts could be available for biomass supply. Forest-based biomass resources may

* Corresponding author. Tel.: +1 413 545 3589; fax: +1 413 545 4358.
E-mail addresses: marla@eco.umass.edu, marla.markowski.lindsay@gmail.com (M. Markowski-Lindsay), cat@umext.umass.edu (P. Catanzaro), ddamery@eco.umass.edu (D. Damery), dbk@eco.umass.edu (D.B. Kittredge), bbutler01@fs.fed.us (B.J. Butler), tstevens@isenberg.umass.edu (T. Stevens).

0301-4797/$ – see front matter
doi:10.1016/j.jenvman.2012.03.051

be unavailable for extraction due to constraints that can be broadly categorized as social or biophysical (Butler et al., 2010). Social availability refers to extraction constraints due to the preferences of individual owners (e.g., their willingness to harvest trees or biomass) and those of the broader society (e.g., regulations that restrict harvesting practices). Biophysical constraints are imposed by nature and include steep slopes, wet soils, and similar conditions. Most of these constraints do not completely negate the probability of resources being extracted, but they do severely reduce the probability of it happening. Other studies have provided estimates of annual dry tons of biomass potential from forest-based sources; for example, a national study by U.S. Department of Energy (2011b) reports that biophysically the U.S. has the resource base needed to successfully undertake biomass harvesting for bioenergy. The study focuses on biomass resources from forests and agricultural land, conducts both a baseline and high-yield scenario, for several time periods, including 2022 (i.e., the year in which revised Renewable Fuels Standard mandates the use of 36 billion gallons per year of renewable fuels). Under the baseline scenario during this time period, of the 914 million dry tons/year of biomass potential, roughly 34% could be derived from forests and 66% from agricultural land. Under the high-yield scenario during this time period, of the 1.2 billion to 1.3 billion dry tons/year of biomass potential, roughly 25% could be derived from forests and 75% from agricultural land.[1] In our study, we expand on the biophysical estimation and present both a socially- and economically-constrained supply of forest-based biomass for bioenergy.

As forest-based biomass industries arise, it will be necessary to determine available biomass supply taking into consideration both social and biophysical constraints. In Massachusetts, private industry has proposed several biomass facilities (currently totaling roughly 200 MW), but little evidence has been presented to address how much could be provided from Massachusetts forest management practices to these biomass "consumers." This analysis considers the level of bioenergy production that could be maintained given the amount of woody biomass that is likely to be supplied from private- and state-owned Massachusetts forests, which comprises nearly 90% of the state's forests. Further, we compare the energy equivalent of our estimates to existing biomass consumers in the state in order to put bioenergy potential into perspective and provide an easily comprehensible sense of scale for the amount of biomass that Massachusetts is likely to provide from its forests. Because it is difficult to determine manageable acreage for municipal forests (i.e., parcels are dispersed reflecting varying land uses), we focus on the ownerships that capture 90% of the forests in the state. Likewise, federal land in Massachusetts is excluded because it comprises such a small portion of total forestland (2%) and would only be a very small contributor to forest-based biomass supply.

2. Background

Massachusetts is the third most densely populated state in the U.S. The residents of Massachusetts live in close proximity to the forestland, resulting in development pressure, and thus leading to smaller parcel size. The majority of forest ownership in Massachusetts is made up of private landowners who own 69% of the forested land in Massachusetts, composed of family owners, trusts, corporations and other private entities (Butler, 2008). The remaining 31% of these forests are publicly held by the State (19%), municipalities (9%), and the federal government (2%) (Butler, 2008).

Harvesting biomass from Massachusetts forests would most often be part of a traditional timber harvest in which multiple products are harvested. Kelty et al. (2008) estimated levels of biomass available from Massachusetts forests from all ownership groups to be 891,000 dry tons/year for owners with holdings of at least 10 ac (4 ha). Since Kelty et al., new information has come to light that indicate much lower supply levels.

Two studies suggest that not all privately-held land would necessarily be available for biomass harvesting. Butler et al. (2010) estimate the biophysical and social availability of wood from family forests in the northern US. The authors estimate that 38% of the family forest owned wood in this region (not biomass) is both biophysically and socially available. Markowski-Lindsay et al. (2011) estimate that between 7% and 17% of Massachusetts family forest owners will harvest biomass as part of a timber harvest using data from a stated preference survey of 932 forest owners holding 10 ac (4 ha) or more. Results from Markowski-Lindsay et al. indicate that biomass harvest characteristics, and landowner activities, beliefs and characteristics play a role in determining the likelihood of harvesting biomass. That study's results indicate that these forest owners are only marginally willing to harvest residual woody biomass as part of a harvesting operation and that willingness is not greatly influenced by a change in price.

Very few other U.S. studies provide estimates of forest-based biomass supply tempered by landowner attitudes. Becker et al. (2010) survey family forest owners in Minnesota to examine what motivates their willingness to supply residual woody biomass. The study found that roughly 60%–70% of landowners, who own an average of 124 ac (50 ha) of forests, would be willing to harvest biomass with prices ranging from $0 per ac to $15 per ac. Factors that influence their willingness to supply biomass include the price of biomass; landowner attitudes, beliefs and characteristics; how far they live from their forested land; and landowner objectives. As noted in Markowski-Lindsay et al. (2011), differences between the Minnesota and Massachusetts studies indicate regional differences in markets, ownership characteristics, biomass harvesting beliefs and preferences. Joshi and Mehmood (2011) consider the availability of logging residues and non-marketable small diameter trees for bioenergy production by southern family forest owners who own more than 20 ac (8 ha) of forestland. Short of estimating a supply curve (the authors exclude the price of biomass from their analysis), the authors find ownership objectives, acreage, species, and respondent age to be important. These studies indicate that when estimating regional biomass availability from privately-owned forests, it is important to consider both social and biophysical constraints.

Further, not all forests owned by the state may be available for biomass harvesting either. In Massachusetts, the Department of Conservation and Recreation (DCR) management objectives for forest devoted to state forests and parks are under review (DCR, 2011). DCR-managed watershed forests and Massachusetts Division of Fisheries and Wildlife (DFW) forests have plans indicating the amount of forests that are available for active management (restricted areas excluded may include, for example, wetlands, steep slopes, protected habitats).

3. Methods

Our study applies the most recent information on forest ownership in Massachusetts and provides an estimated range of biomass availability for bioenergy from state and private forests. To do this, we estimated overall forested acreages, reduced these by social and biophysical constraints, and then estimated how many dry tons/ac of biomass that private and state-owned forests would sustainably yield on a continuous basis each year. We acknowledge that there is a flow of wood between nearby states and that these results exclude supply from other activities such as land clearing

[1] The results for both of these scenarios reflect $60 per dry ton or less.

and waste wood; however it is our goal to provide information on Massachusetts-based forest supply.

3.1. Private forests

Massachusetts has 290,000 family forest owners whose ownership is dominated by small parcel size (Butler, 2008). These families place low priority on timber income from their land, and their owner preferences are focused primarily on passive benefits, such as aesthetics, recreation, nature, and privacy (Butler, 2008).

To estimate the biomass supply from privately-held forests, we focused on properties of 10 ac (4 ha) or more. The 10 ac cutoff was determined based on existing harvesting data and standards set for current relevant forest policy in the state. In particular, Kittredge et al. (1996) surveyed professional loggers in Massachusetts to determine their sensitivity to small harvest opportunities, either by volume or area. Respondents indicated they had purchased a sale as small as an average of 8 acres and 20 Mbf. In addition, Massachusetts has a current use property tax program (Chapter 61) for owners of at least 10 ac of contiguous forestland interested in keeping their land in its current undeveloped use. Chapter 61 requires long-term, sustainable timber management based on a state-approved management plan that must be renewed every 10 years in exchange for a reduced forestland valuation. Owners of fewer than 10 ac do not qualify to participate in this program. Moreover, the size of forest holdings has been shown to be positively related to the probability of harvesting (Beach et al., 2005; McDonald et al., 2006); the smaller the landholding size, the less likely that timber harvest (and perhaps biomass removal) would occur. Taken together, this information suggests a relationship between small landholding size and unlikely nature of timber/biomass harvesting. As a result, we focused on owners who own a minimum of 10 ac.

First, we estimated the amount of acreage available from existing surveys of privately-owned forests in the state (Kittredge et al., 2008 and Butler, 2008). Kittredge et al. (2008) estimate that Massachusetts has 38,798 family forest owners who own 10 forested ac or more (representing 82% of family forest owners), with an average parcel size of 42.5 ac. Butler (2008) estimates that Massachusetts has 3000 "other private" owners (e.g., land trusts, corporations) with an average parcel size of 164.3 ac.

Second, to reflect the preferences private forest owners have for biomass harvesting, we estimated the acreage of private forests socially available for biomass harvesting. Markowski-Lindsay et al. (2011) estimate the willingness to harvest residual woody biomass as part of a timber harvest for private forests in Massachusetts. Markowski-Lindsay et al. results indicate that 7%, 10% and 17% of family forest owners in Massachusetts, who own a minimum of 10 ac (4 ha), would be willing to harvest residual woody biomass as part of a timber harvest when presented with net revenues based on \$0/ton, \$4/ton and \$8/green ton stumpage. The net revenue values (\$0/ac to \$500/ac) span the range of actual Massachusetts stumpage prices for biomass from 2007 through 2010, and include those outside the current market range. We applied the 7%, 10%, and 17% participation rates from Markowski-Lindsay et al. (2011) to the Kittredge et al. (2008) estimates of family forest owners and acreage and estimated that approximately 2720–6600 family forest owners would be willing to harvest approximately 115,425 to 280,315 ac (46,711 to 113,440 ha). Assuming these same participation rates for other private forest owners, this represents 210 to 510 other private forest owners who would be willing to harvest approximately 34,505 to 83,795 ac (13,964 to 33,911 ha). The vast majority of entities in the "Other Private" category are NGOs (e.g., land trusts make up many "Other Private" owners in Massachusetts), unincorporated clubs (e.g., gun clubs, hunting clubs), Native American tribes and corporate owners (e.g., individual companies with acreages behind their plants). The number of owners in the forest industry category is negligible, if not zero (according to Butler (2008)). In Massachusetts, "Other Private" owner objectives are much more similar to families and individuals than to other ownership groups. Based on this evidence, we make the assumption that "Other Private" owners are not those with strong timber management motivations, but with motivations more reflective of individuals and families. These acreages reflect the amount of land that is socially available for harvesting (i.e., owners who may be interested) and do not include the physical limitations of the site.

Third, we ensured that these estimates have removed acreages reflecting biophysical limitations for harvesting (e.g., steep slopes, wet soils). We relied on Butler et al. (2010) for estimates of biophysical limitations associated with privately-held Massachusetts forests. Butler et al. (2010) estimate the biophysical and social availability of wood from family forests in the North (i.e., the 20 state region including and between Maine, Maryland, Missouri, and Minnesota). We applied this study's biophysical constraint result of 6% for Massachusetts to our estimated acreage numbers to estimate approximately 140,930 to 342,260 ac (57,032 to 138,508 ha) from all private forest owners. While Butler et al. (2010) also estimated a social availability of wood (not biomass) in the North, we did not apply this result. We applied the Markowski-Lindsay et al. (2011) result because it reflected private owner preferences for harvesting biomass for bioenergy purposes, as opposed to the broader concept of the availability of wood. Note that there is uncertainty from the individual landowner about whether to harvest and, if harvesting, how much to harvest. Family forest owner surveys indicate harvesting to be a very low priority (e.g., Butler, 2008; Belin et al., 2005; Finley and Kittredge, 2006; Rickenbach et al., 1998); however over half commercial timber sales by area in the state over 20 years come from family forestlands (McDonald et al., 2006). Data from Markowski-Lindsay et al. (2011) indicate that Massachusetts family forest owners who say they would harvest report this would apply to a range of between 3% and 99% of their total forested acreage.

Finally, we applied the results of Kelty et al.'s (2008) analysis of the sustainable level of forest-based biomass harvesting in Massachusetts to estimate biomass supply. Kelty et al. (2008) use the Northeast Forest Vegetation Simulator (FVS) developed by the U.S. Forest Service (Teck and Hilt, 1991), a growth and yield model, to estimate how many dry tons/ac of biomass that private and publicly-held forests would sustainably yield on a continuous basis each year. Kelty et al. define sustainable yield as the total harvest per year that does not exceed total net growth per year. We applied the biomass growth rate of 0.89 dry tons/ac/year for private forests (including sawtimber) to our private forest acreage estimates. Following Kelty et al. (2008), we removed sawtimber tonnage (36%) to estimate 80,275 to 194,950 dry tons/year from private forests.

For family forestland, this is likely to be the maximum amount of forest cover to be used for biomass harvesting for the foreseeable future. As more forestland is converted to non-forest use or subdivided, there will be less opportunity to produce wood products, including biomass. In addition, these estimates would be reduced if Massachusetts' regulations that currently guide the amount of biomass removed to support a power plant were extended to other end uses; because not all biomass removal is regulated, the above estimates do not include regulatory restrictions. Table 1 summarizes these results.

3.2. State-owned forests

The state-owned forests in Massachusetts can be categorized into DCR forests (state forests and parks and watershed forests (i.e.,

Table 1
Biomass supply scenarios from Massachusetts private and state-owned forests.[a]

	Private forests			State-owned forests			Total		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Available acres (hectares)	140,931 (57,033)	201,331 (81,476)	342,262 (138,509)	0 (0)	145,009 (58,683)	290,018 (117,366)	140,931 (57,033)	346,340 (140,159)	632,280 (255,875)
Dry tons of biomass/year[b]	80,275	114,678	194,952	0	87,237	174,475	80,275	201,915	369,427
Trillion BTUs/year	1.4	1.9	3.3	0	1.5	2.9	1.4	3.4	6.2
MW	15	22	37	0	17	34	15	39	71

[a] While a variety of assumptions go into the dry tons of biomass/year estimation, the ones defining the low, medium and high scenarios are as follows: private owner participation in biomass harvesting set at 7%, 10%, or 17%; percent of state-owned forest available for active management set at 0%, 40%, or 80%.
[b] Massachusetts' current regulations only guide the amount of biomass removed to support a power plant. Because not all biomass removal is regulated, the above estimates do not include regulatory restrictions.

forests owned by the state surrounding public water supplies)) and DFW forests. To estimate the biomass supply from state-owned forests, our analysis recognizes the uncertainty surrounding the amount of forests owned by the state that could be available for biomass harvesting. The sections below apply a range of estimates to the total amount of forests available for active management from each state agency. Current policy debate on DCR state forests and parks indicates between 0% and 40% of forests would be available for active management (DCR, 2011); we also considered an upper bound of 80% to model supply far beyond the current debate. We applied these three scenarios to DCR and DFW actively managed forests for illustrative purposes only.

For DCR's state forests and parks, we estimated the acreage available for active management directly from DCR personnel. The DCR's state forests and parks acreage includes forests which total 280,000 ac (113,312 ha) (David Goodwin, pers. comm., Assistant Program Manager, DCR, May 5, 2011). Because the policy debate surrounding this land is in-process, the exact number of forested acres that can be managed is not known; however, there are a number of likely biophysical constraints which include steep slopes, wetlands, and endangered species habitats that will likely at least partially constrain management. Applying these constraints from the total acres leaves 195,000 ac (78,914 ha) available for active management (David Goodwin, pers. comm., Assistant Program Manager, DCR, May 5, 2011). We applied the illustrative ranges above (i.e., 0%, 40%, 80%) to this actively managed acreage and estimated that the amount of DCR state forests and parks available for biomass harvesting could range from 0 to 156,000 ac (0 to 63,131 ha).

For DCR watershed forests, we estimate the acreage available for active management from existing state reports. DCR watershed forests include approximately 77,522 ac (31,372 ha). This acreage derives from the Quabbin reservoir, Wachusett reservoir, Ware River, and Sudbury reservoir land management plans that already exclude restricted land (e.g., steep slopes, wetlands, protected habitats) (Commonwealth of Massachusetts, 2001, 2003, 2005, 2007). We applied the illustrative ranges above (i.e., 0%, 40%, 80%) to the actively managed acreage and estimated that the amount of DCR watershed forests available for biomass harvesting would range from 0 to 62,020 ac (0 to 25,099 ha), given our assumptions.

For DFW forests we estimated the acreage available for active management from DFW reports. DFW is expected to own 158,000 ac (63,940 ha) by June, 2011 (Brian Hawthorne, pers. comm., Massachusetts DFW, April 25, 2011). DFW forest open to active management (excluding, for example, steep slopes, wetlands and protected habitats) is roughly 90,000 ac (36,422 ha) based on the current 57% of manageable land (Commonwealth of Massachusetts, 2008). We applied the above illustrative ranges (i.e., 0%, 40%, 80%) to manageable acres and estimate that the amount of DFW forests available could range from 0 to 72,000 ac (0 to 29,137 ha).

Similar to our methodology for private forests, we applied the results of Kelty et al.'s (2008) analysis of the sustainable level of forest-based biomass harvesting in Massachusetts to estimate biomass supply. Kelty et al. (2008) estimate a mean biomass growth rate of 0.94 dry tons/ac/year (including sawtimber) for publicly-owned forests in Massachusetts. We applied this growth rate to our state-owned forest acreage estimates. Following Kelty et al.

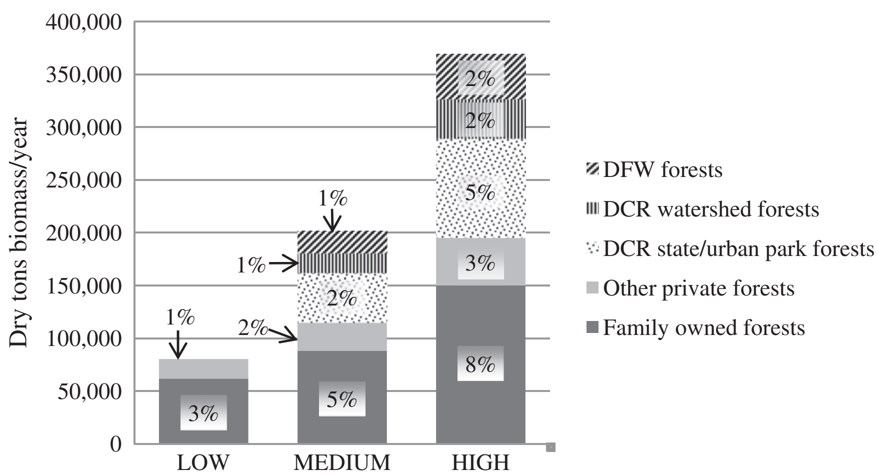

Fig. 1. Dry tons forest-based biomass per year by source and scenario.[a] This figure summarizes the total dry tons of forest-based biomass per year by illustrative forest management scenario and by state and private ownership. DCR: Massachusetts Department of Conservation and Recreation; DFW: Massachusetts Division of Fisheries and Wildlife (DFW).

Table 2
Energy equivalence of sustainable forest-based biomass supply to existing bioenergy consumers in Massachusetts.

Existing bioenergy in Massachusetts		Equivalence by scenario[a]		
Bioenergy source	Capacity	Low	Medium	High
Fitchburg Pinetree Plant	17 MW	1 plant	2 plants	4 plants
Mt. Wachusett Community College (450,000 ft^2 facility)	660 dry tons/year[b,c]	122 colleges	306 colleges	560 colleges
Cooley Dickinson Hospital (600,000 ft^2 facility)	8000 dry tons/year[c,d]	10 hospitals	25 hospitals	46 hospitals
Stow Greenhouse (35,000 ft2 facility)	1123 dry tons/year[c,e]	72 greenhouses	180 greenhouses	329 greenhouses
Quabbin Administration Building (40,000 ft^2 facility)	192.5 dry tons/year[c,f]	417 buildings	1049 buildings	1919 buildings
Athol High School (89,440 ft^2 facility)	204 dry tons/year[c,g]	393 high schools	990 high schools	1810 high schools
Cordwood, assuming average home uses 3 cords per year	4.3 dry tons/home[h]	18,750 homes	47,200 homes	86,300 homes

[a] While a variety of assumptions go into the dry tons of biomass/year estimation, the ones defining the low, medium and high scenarios are as follows: private owner participation in biomass harvesting set at 7%, 10%, or 17%; percent of state-owned forest available for active management set at 0%, 40%, or 80%.
[b] Based on 1200 green tons/year (Mount Wachusett, 2011).
[c] Dry tons/year calculation based on 45% moisture content (INRS, 2007).
[d] Based on 40 green tons/day (John Lombardi, pers. comm., Director of Facilities/Engineering Cooley Dickinson Hospital, April 20, 2011).
[e] Based on 2750 cu. yards green chips/year (University of Vermont Extension, 2011); cubic yard to pound conversion from U.S. EPA (2011).
[f] Based on 350 green tons/year (BERC, 2011).
[g] Source of facility size and 371 green tons/year: Robert Rouleau, pers. comm., Director Facilities/Transportation Athol-Royalston Regional School District, April 27, 2011.
[h] Capacity based on 24 MMBTU/cord (University of Maine, 2008); 9.25 MMBTU/ton of green chips and 45% moisture content (INRS, 2007); and authors assume the average home uses 3 cords of wood per year.

(2008), we removed sawtimber tonnage (36%) to estimate between 0 and 174,500 dry tons/year from forests owned by the state. Table 1 summarizes these results.

3.3. Energy conversion

To provide supply estimates that enable comparison with electricity-generating biomass facilities, we converted the estimated dry tons of biomass/year supply estimates to megawatts (MW). Converting biomass estimates to MWs assumes biomass is solely used for electricity generation. In addition, it is important to recognize that the parameters of this conversion are sensitive to measures of plant efficiency, technology and fuel characteristics. The conversion parameters used are based on INRS (2007) and Massachusetts Renewable Energy Portfolio Standard draft regulation (Commonwealth of Massachusetts, 2011). These parameters resulted in 5207 dry tons of biomass/year supplying 1 MW of electricity. We applied this conversion to our total biomass supply estimates from private and state-owned forests; these forests could sustainably supply 15 MW, 39 MW, or 71 MW, depending on scenario (Table 1).

4. Results

Our analysis estimated that between 80,275 and 369,000 dry tons/year of forest-based biomass would be available from private- and state-owned forests, depending on scenario considered (See Table 1). The results indicate that family-owned forests produce more total dry tons of biomass per year than other ownership categories for each scenario. The amount of actively managed land for harvesting timber and biomass ranges from 4% to 20% of all Massachusetts forests, depending on scenario. Fig. 1 summarizes these results.

Our scenarios estimated between 1.4 trillion and 3.3 trillion BTUs/year potential from sustainable biomass supply from private forests, and between 0 and 2.9 trillion BTUs/year potential from forests owned by the state (see Table 1). We estimated these BTU potentials based on INRS (2007) characteristics of logging residue-based biomass fuels: 45% moisture content and 4625 BTU/lb.

To put bioenergy potential into perspective and to provide an easily comprehensible sense of scale for the amount of biomass that Massachusetts is likely to provide from its forests, we compared the energy equivalent of our estimates to existing biomass consumers in the state. In particular, we compared the dry tons/year of biomass used from each reported biomass consumer to the total dry tons/year of biomass we estimated for the low, medium and high scenarios. There is one exception to this rule – for the Fitchburg Pinetree Plant we compare estimated MW for the low, medium and high scenarios (Table 1). Table 2 provides examples of these consumers, their capacity, and how many of these could be provided given the low, medium, and high estimated scenarios.

5. Conclusion

This study estimated dry tons of biomass/year likely to be available from private and state-owned forest resources in Massachusetts. The estimated range (80,275–369,000 dry tons/year) is well below Kelty et al.'s (2008) estimate of 891,000 dry tons/year. The largest factors in this reduction are the reduced contribution of biomass due to social constraints (e.g., harvesting intentions, family forest owner attitudes toward the economic impact of biomass harvesting) and the amount of state land considered to be open to active management based on policy decisions driven by the political process. Further, our estimated range approaches the lower bound of the Manomet (2010a) estimates for both the low- and high-price scenario (82,500 and 376,750 dry tons/year) using a different methodology. Manomet (2010a) estimates forest-based biomass supply from harvesting on public and private lands in Massachusetts. The Manomet estimates of forest-based biomass availability are based, in part, on historical harvesting practices, not direct elicitation of landowner preferences.

Our novel approach refines the estimates of biomass availability by incorporating, in particular, more information about forest owner attributes than has been done before. Kelty et al. (2008) started the discussion with their estimate. Butler et al. (2010) generated estimates for the North that incorporated reflections of social constraints and private landowner attitudes for supplying wood. Markowski-Lindsay et al. (2011) further refine the concept of available supply based on results of a survey designed to assess specific private landowner attitudes toward biomass in Massachusetts. Our study brings together information from these and other sources to estimate forest-based biomass supply from 90% of the forests in the state reflecting both social and biophysical constraints. While we share the same message as these previously published studies, our paper extends that work by putting forest-based biomass energy into the context of total consumption. We built upon these previous efforts to address the issue of forest-based biomass supply and produce results that are beyond mere speculation.

Massachusetts residential, commercial, and industrial sources consume 1475 trillion BTUs/year (U.S. DOE, 2011a).[2] Our estimated scenarios suggest that a sustainable forest-based biomass supply could potentially provide between 1.4 trillion BTUs/year (low scenario) and 6.2 trillion BTUs/year (high scenario). This BTU potential reflects between 0.09% and 0.42% of Massachusetts' residential, commercial, and industrial annual consumption. Our energy estimates are based on harvesting biomass from 4% to 20% of the available forested land in the state. Because significant limiting factors on biomass availability are attitudinal (e.g., Butler et al., 2010) and based on the limitations of harvesting (i.e., property size and regulations) (e.g., Kittredge et al., 1996), we believe that conditions that could change our estimates include: landowner attitudes (e.g., due to price, incentives, beliefs about renewable energy), landowner awareness of harvesting practices, biomass regulations, land conversion and parcelization.

Clearly, at the BTU level, statewide a sustainable forest-based biomass supply does not significantly contribute to total Massachusetts annual energy consumption; however, a comparison of the energy equivalent of our estimates to existing biomass consumers in the state (Table 2) shows that forest-based biomass supply plays a considerable role at the local level, for schools, businesses, and municipalities. This outcome leads us to believe that forest-based biomass supply could be a meaningful contributor in rural areas where BTU needs are low in comparison to the state average.

Estimating forest-based biomass supply in Massachusetts provides information for the debate among policymakers, the public, foresters, and private industry in the state. For policymakers, our study shows the likely scale of biomass removal from Massachusetts forests and can help guide policies and regulations. Specifically, for regions with similar timber markets, ownership characteristics and socioeconomic circumstances to Massachusetts, our results suggest policies that support small-scale local facilities. Statewide, forest-based biomass supply may not make a huge impact, but at the local level it may help the forests (e.g., by expanding a market for low-grade materials), landowners (e.g., by providing additional income), local economies (e.g., by generating local jobs), and local users (e.g., by allowing them (perhaps) to save money by consuming locally at a school or municipal building). Broadly, our analysis suggests that policymakers would be well-advised to consider analyses such as ours that estimate not only biophysical availability but social availability, as well. Policymakers who only consider tonnage estimated by Forest Inventory and Analysis (FIA) or other timber inventory sources, and do not consider the social context of private ownership and the variability of supply from public lands, will seriously overestimate availability and potentially "overbuild" policies. For private industry, our results show the level of interest in this market and perhaps help to gauge how reliable this renewable energy source would be for Massachusetts. Our methods benefit industry decision-makers with a means to obtain better estimates of local resource supply and its implications on raw material input supply logistics for any given project. For the public, it suggests that Massachusetts won't likely lose all of its forests to biomass harvesting, as has been suggested by some. This result is not surprising because Massachusetts forest ownership is dominated by private landowners who put great importance on amenity benefits such as privacy, aesthetics and recreation (Butler, 2008). Other forested landscapes dominated by private owners with similar attitudes and beliefs about the use of their land and their willingness to harvest biomass may also show a significantly constrained forest-based biomass supply. It is important to note that our study is not an environmental impact analysis and only addresses the forest-based supply side of this discussion.

Conversations regarding the use of biomass and its impacts on forests, as well as the development of biomass-related policy, should consider the supply of biomass that is likely available. While overall forest inventory estimates suggest one degree of availability, past research suggests that this needs to be tempered with the reality of ownership size and owner attitudes. Our research adopts these assumptions from past findings and shows a significantly decreased availability of forest-based biomass for bioenergy for Massachusetts. Indeed, the social economic supply of forest-based biomass for bioenergy is likely to differ across the U.S. Differences in regional timber markets, social factors, forest types and state biomass bioenergy policy all contribute to a differing impact on biophysical availability. Given the current federal policies that exist to underscore the important role that private forests may play in the future of biomass for bioenergy (e.g., Energy Policy Act of 2005, Energy Independence and Security Act of 2007, and 2008 U.S. Farm Bill), it is increasingly important to gain a more realistic understanding of the supply of forest-based biomass for bioenergy. The methods presented in this article could be used to estimate regional forest-based biomass availability in other regions.

States and countries are poised to make important energy policy decisions in the 21st century. Failure to consider the social implications of forest-based biomass supply could lead to policy mistakes. Key to developing successful policies is conducting applied research on the social implications of these resource questions. The methodology provided in this paper presents a means to incorporate more information about forest owner attributes, resulting in forest-based biomass supply estimates that reflect both social and biophysical constraints. This methodology could be applied elsewhere to estimate supply levels that are beyond mere speculation.

Funding source

This material is based upon work supported by the National Institute of Food and Agriculture, U. S. Department of Agriculture, the Massachusetts Agricultural Experiment Station and the Department of Environmental Conservation, under Project No. MAS009582. The U.S. Department of Agriculture, Massachusetts Agricultural Experiment Station and the Department of Environmental Conservation assisted in the study design; data collection, analysis, and interpretation; report writing and decision to submit for publication.

References

Beach, R.H., Pattanayak, S.K., Yang, J.-C., Murray, B.C., Abt, R.C., 2005. Econometric studies of non-industrial private forest management: a review and synthesis. Forest Policy and Economics 7, 261–281.

Becker, D.R., Klapperich, J.J., Domke, G.M., Kilgore, M.A., D'Amato, A.W., Current, D.A., Ek, A.R., 2010. 2010 Outlook for Forest Biomass Availability in Minnesota: Physical, Environmental, Economic, and Social Availability. Department of Forest Resources, College of Food, Agricultural and Natural Resource Sciences, University of Minnesota, St. Paul, 83 pp.

Belin, D.L., Kittredge, D.B., Stevens, T.H., Dennis, D.F., Schweik, C.M., Morzuch, B.J., 2005. Assessing NIPF owner attitudes toward forest management. Journal of Forestry 103, 28–35.

Biomass Energy Resource Center (BERC), 2011. Quabbin Administration Building, Belchertown, Massachusetts, United States – Woodchip System at Quabbin Ignites Interest in Massachusetts. http://www.biomasscenter.org/portfolio/165-quabbin.html (Last accessed 02.05.11.).

[2] Excluded from this figure is the Massachusetts transportation sector, which consumes 489 trillion BTUs/year (U.S. DOE, 2011a).

Butler, B.J., 2008. Family Forest Owners of the United States, 2006, Gen. Tech. Rep. NRS-27. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, 72 pp.
Butler, B.J., Ma, Z., Kittredge, D.B., Catanzaro, P.F., 2010. Social versus biophysical availability of wood in the northern United States. Northern Journal of Applied Forestry 27, 151–159.
Commonwealth of Massachusetts, 2001. Wachusett Reservoir Watershed Land Management Plan: 2001–2010. Metropolitan District Commission, Division of Watershed Management, 216 pp.
Commonwealth of Massachusetts, 2003. Ware River Watershed Land Management Plan 2003–2012. Department of Conservation and Recreation, Division of Water Supply Protection, 205 pp.
Commonwealth of Massachusetts, 2005. Land Management Plan for the Watersheds of the Sudbury Reservoirs: 2005–2014. Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management, 160 pp.
Commonwealth of Massachusetts, 2007. Quabbin Reservoir Watershed System: Land Management Plan 2007–2017. Department of Conservation and Recreation, Division of Water Supply Protection, Office of Watershed Management, 341 pp.
Commonwealth of Massachusetts, 2008. Appendix VI – Forest Inventory and Estimate of Annual Sustainable Harvest on Mass Wildlife Forests, September 22, 2008. Executive Office of Energy & Environmental Affairs, Division of Fisheries and Wildlife, Biodiversity Initiative - Forestry Program, 21 pp.
Commonwealth of Massachusetts, 2011. Massachusetts Renewable Energy Portfolio Standard – Class I, 225 CMR 14.00. Draft Regulation filed on May 3, 2011. Department of Energy Resources, 33 pp.
Department of Conservation and Recreation (DCR), 2011. Forestry – Forest Futures Visioning Process. www.mass.gov/dcr/news/publicmeetings/tsc_final_recommendations.htm (Last accessed 27.04.11.).
Finley, A.O., Kittredge Jr., D.B., 2006. Thoreau, Muir, and Jane Doe: different types of private forest owners need different kinds of forest management. Northern Journal of Applied Forestry 23, 27–34.
Innovative Natural Resource Solutions LLC (INRS), 2007. Biomass Availability Analysis – Five Counties of Western Massachusetts. Prepared for the Massachusetts Division of Energy Resources & Massachusetts Department of Conservation and Recreation, 55 pp.
Joshi, O., Mehmood, S.R., 2011. Factors affecting nonindustrial private forest landowners' willingness to supply woody biomass for bioenergy. Biomass and Bioenergy 35, 186–192.
Kelty, M.J., D'Amato, A.W., Barten, P.K., 2008. Silvicultural and Ecological Considerations of Forest Biomass Harvesting in Massachusetts. Prepared for Massachusetts Division of Energy Resources and Massachusetts Department of Conservation and Recreation, 65 pp.
Kittredge, D.B., D'Amato, A.W., Catanzaro, P., Fish, J., Butler, B., 2008. Estimating ownership and parcels of nonindustrial private forestland in Massachusetts. Northern Journal of Applied Forestry 25, 93–98.
Kittredge Jr., D.B., Mauri, M.J., McGuire, E.J., 1996. Decreasing woodlot size and the future of timber sales in Massachusetts: when is an operation too small? Northern Journal of Applied Forestry 13, 96–101.
Leonard, M., Kim, S., 2011. Better Forest Management: Why Biomass has Place in Equation. 03/24/2011. The Recorder, Greenfield, MA.
Manomet Center for Conservation Sciences (Manomet), 2010a. Massachusetts Biomass Sustainability and Carbon Policy Study: Report to the Commonwealth of Massachusetts Department of Energy Resources. Natural Capital Initiative Report NCI-2010-03, Brunswick, ME.
Markowski-Lindsay, M., Stevens, T., Kittredge, D.B., Butler, B.J., Catanzaro, P., Damery, D., 2011. Family forest owner preferences for biomass harvesting in Massachusetts. Forest Policy and Economics. doi:10.1016/j.forpol.2011.08.001.
McDonald, R.I., Motzkin, G., Bank, M.S., Kittredge, D.B., Burk, J., Foster, D.R., 2006. Forest harvesting and land-use conversion over two decades in Massachusetts. Forest Ecology and Management 227, 31–41.
Mount Wachusett Community College (Mount Wachusett), 2011. Biomass Conversion Fact Sheet. http://www.mwcc.mass.edu/renewable/conversionfacts.html (Last accessed 03.05.11.).
Rickenbach, M.G., Kittredge, D.B., Dennis, D., Stevens, T., 1998. Ecosystem management: capturing the concept for woodland owners. Journal of Forestry 96, 18–24.
Teck, R.M., Hilt, D.E., 1991. Individual-tree Diameter Growth Model for the Northeastern United States. U.S. Forest Service, Research Paper NE-649, 11 pp.
U.S. Department of Energy (U.S. DOE), 2011a. Energy Efficiency and Renewable Energy. http://www.epa.gov/osw/partnerships/wastewise/publs/conversions.pdf (Last accessed 27.04.11.).
U.S. Department of Energy (U.S. DOE), 2011b. U.S. Billion-ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry. R.D. Perlack and B.J. Stokes (Leads), ORNL/TM-2011/224. Oak Ridge National Laboratory, Oak Ridge, TN. 227 p.
U.S. Environmental Protection Agency (U.S. EPA), 2011. Standard Volume-to-weight Conversion Factors. http://www.epa.gov/osw/partnerships/wastewise/pubs/conversions.pdf (Last accessed 03.05.11.).
University of Maine, 2008. How much Heat per Dollar? Prepared by Associate Extension Professor Donna Coffin. http://umaine.edu/publications/7216e (Last accessed 02.05.11.).
University of Vermont Extension, 2011. On-farm Energy Case Study Waste Wood Chips for Greenhouse Heat. Stow Greenhouses – Stow, MA. http://www.uvm.edu/vtvegandberry/pubs/Waste%20Wood%20Chips%20for%20Greenhouse%20Heat.pdf (Last accessed 03.05.11.).