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Forest Biomass Utilization in the Southern United States: Resource Sustainability and Policy Impacts

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To the Graduate Council:

I am submitting herewith a dissertation written by Zhimei Guo entitled "Forest Biomass Utilization in the Southern United States: Resource Sustainability and Policy Impacts." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Natural Resources.

Donald G. Hodges, Major Professor

We have read this dissertation and recommend its acceptance:

Christopher D. Clark, Christian A. Vossler, Timothy M. Young

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Christian A. Vossler, Associate Professor

Timothy M. Young, Professor

Accepted for the Council:

Carolyn R. Hodges, Vice Provost and
Dean of the Graduate School

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Forest Biomass Utilization in the Southern United States:

Resource Sustainability and Policy Impacts

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

Zhimei Guo

May 2011

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ABSTRACT

As an alternative renewable source for bioenergy, forest biomass has recently drawn more attention from the U.S. government and the general public. Woody biomass policies have been adopted to encourage the new bioenergy industry. A variety of state policy incentives attempt to create a desirable legal climate and lure new firms, imposing two important questions regarding state government policies and the sustainable use of forest resources. This dissertation sheds some light on these questions.

The first paper constructs a woody biomass policy index through scoring each statute and weighting different categories of policies from the vantage point of renewable energy investment. It analyzes the disparity in the strength of state government incentives in the woody biomass utilization. The second paper employs a conditional logit model (CLM) to explore the effects of woody biomass policies on the siting decisions of new bioenergy projects. In addition, significant state attributes influencing the births of new bioenergy firms are identified such as resource availability, business tax climate, delivered pulpwood price, and the average wage rate. The third paper uses the Sub-Regional Timber Supply (SRTS) model to examine the regional aggregate forest biomass feedstock potential in Tennessee and to predict the impacts of additional pulpwood demand on the regional roundwood market through 2030. The fourth paper includes the benefits of thinning and logging residues in a dynamic optimization model to analyze how bioenergy policies will impact forest stock, harvest levels, optimal rotation, and silvicultural effort.

The results may have substantial implications regarding woody biomass policies, the creation of a new bioenergy industry, and sustainable forest resource management. A lucrative state woody biomass policy support and tax climate can attract new bioenergy businesses. States endowed with abundant forest resources may choose to provide strong tax incentives to spur the birth of new plants. However, overuse of forest biomass can impact roundwood markets and traditional wood processing industries. How government incentives will affect the sustainability of natural resources can be diverse. These findings offer constructive insights in the enactment and implementation of new woody biomass legislation.

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Chapter 1

Introduction

Interest in renewable energy has been growing since the 1970s due to public concerns over energy prices, global climate change, and air quality. One source of renewable energy is biomass, which is largely categorized as agricultural or forest biomass. Given various governmental incentives, the industrial production of bio-based transportation fuels has relied primarily on agricultural crops such as corn and soybeans for the past few decades. In recent years, however, more attention has been drawn toward forest biomass for bioenergy because of the potential problems of relying on agricultural biomass, with national and state governments implementing a variety of policies to stimulate woody biomass utilization.

Using forest biomass for bioenergy will reduce the burden of biofuel production on agricultural lands, spur regional economic growth, and maintain social sustainability. However, what will be the sustained yield of forest biomass? Its availability varies significantly across different regions. Also, regional forest resource trends and competition from other wood products will affect biomass availability. It is unlikely that harvesting residues will meet the demand for woody feedstocks in all regions. For example, a recent study suggested that logging residues are insufficient in two of the three states examined (Galik et al. 2009). This situation will result in an increased demand for pulpwood which is currently used for other wood products. Therefore, it is necessary to investigate the interaction of wood markets with the emerging market for forest biomass, as well as the impacts of forest biomass utilization on the sustainability of roundwood markets.

Since 2000, various federal regulations and programs have been established to stimulate the use of forest-derived biomass, especially small-diameter wood, to reduce the danger of wildfire, maintain forest health, and diversify the domestic energy supply. These include the Biomass Research and Development Act of 2000, the National Fire Plan of 2000, the Farm Bill of 2002, the Healthy Forest Restoration Act of 2003, the Omnibus Appropriations Bill of 2003, the Energy Policy Act of 2005, and the Farm Bill of 2008. Legislation has addressed the challenges of biomass procurement, improvement of ligno-cellulosic conversion technologies, and bio-product market development (Guo et al. 2007).

State and local policies also have been enacted to provide financial and other incentives to woody biomass utilization. Becker and Lee (2008) established a state woody biomass policy database based on the Database of State Incentives for Renewable Energy (DSIRE) (NCSS and IREC 2009). The number and category of incentives provided by different states vary. Together with environmental protection policies, these incentives may strongly influence the siting decision of new bioenergy plants. However little is known about how these state and local statutes, as well as environmental protection policies, will affect the establishment of new bioenergy industries and sustainable regional forest biomass supply.

My research focuses on the use of forest biomass for bioenergy production in the southern United States. The specific objectives are to (1) create a woody biomass policy index to compare the states in terms of the strength of policy incentives; (2) examine how state incentives as well as environmental protection policies affect bioenergy plant establishment; (3) investigate the impacts of various forest biomass utilization scenarios on regional roundwood markets and forest biomass availability; and (4) explore the potential effects of bioenergy policies on the optimal forest stock and harvest.

The dissertation is organized as follows. Chapter II contains a review of state regulations and programs relevant to woody biomass utilization in the 50 U.S. states, and a policy index that was created through weighting each category of policies and scoring each statute. The states were then compared, and the strengths of policy incentives for each state discussed. Chapter III employs an economic model to examine the impacts of state woody biomass policies on new bioenergy plant location decisions. Chapter IV applies the Sub-regional Timber Supply (SRTS) model to predict the trend of future roundwood markets with additional demand of pulpwood for biorefinery production in Tennessee. Changes in forest inventory, removals, and wood product prices were assessed as indicators to reveal regional resource sustainability. Chapter V considers the benefits of thinning and logging residues in a dynamic optimization model to analyze how bioenergy policies will impact the optimal steady state forest stock, harvest levels, rotation, and silvicultural effort. Finally, Chapter VI provides a summary and conclusions for the dissertation.

Chapter 2

Woody Biomass Utilization Policies: State Rankings

Abstract

Most state governments have adopted state programs and laws recently that provide fiscal incentives and non-fiscal supports for renewable energy projects in the hope that they will encourage the establishment of new bioenergy industry and economic growth. This research analyzes the disparity in the strength of state government incentives in the use of woody biomass. A woody biomass policy index was created through scoring each statute and weighting different categories of policies based on the potential effects on site location decisions. Results indicate that as of 2008 Iowa, North Carolina, and Washington provided the strongest incentives, whereas Wyoming, Mississippi, and Virginia offered the weakest support to the bioenergy industry using woody biomass. This index is not only helpful for new business investors in making siting decisions, but also for state policy makers considering new woody biomass relevant legislation to spur the bioenergy industry.

Keyword: government incentives, policy index, ranking, renewable energy investment, strength

Introduction

Federal and state governments have been adopting policies to stimulate the development of renewable energy since the 1970s. Early legislation strongly encouraged the use of agricultural biomass such as corn and soybeans for transportation fuels. Recent reports, however, have identified the potential problems associated with large-scale biofuel production from crops including the fluctuation of crop prices and insufficient biomass supply (Ford and Senauer 2007). The growth of biofuel production has increased prices of corn and other grains. Even food products such as peas and sweet corn may be affected eventually because of the increased prices. As a result, agricultural lands will not be able to meet the growing demand.

Government agencies and producers have turned to woody biomass as an alternative renewable source as a result of the problems posed by agriculture. In recent years, various federal policies and programs have been established to stimulate the use of forest-derived biomass, especially small diameter wood, to reduce the danger of wildfire, maintain forest health, and diversify the domestic energy supply (Guo et al. 2007). Legislation has addressed the challenges of biomass procurement, improvement of lingo-cellulosic conversion technologies, and bio-product market development. Following the federal lead, states have also started their own initiatives for woody biomass utilization.

A variety of state policies and programs provide fiscal incentives and non-fiscal supports for renewable energy projects using forest biomass. The number and category of policies varies considerably by state. Some states have strong tax incentives, while others offer attractive loan programs or consultation support to lure new bioenergy businesses. These policies have driven the construction of new biorefinery projects in many states such as North Carolina, Florida, Georgia, and Wisconsin.

Becker and Lee (2008) established a state woody biomass policy database, which presents brief information on each policy for all individual states. Yet, no one has assessed these policies to determine their effect and provide policy makers with an evaluation of which incentives are the most effective for attracting forest biomass facilities. Such an analysis will also be useful for the emerging bioenergy industry in making plant siting decisions. Previous research has also compared the environmental stringency of each state through ranking environmental regulations (FREE, 1987; Hall and Kerr 1991). Some studies have indicated that there is a significant relationship between the environmental regulation index and economic or employment growth (Levinson 2001; Jeppesen and Folmer 2001). A variety of indices and rankings have been created to measure the economic competitiveness among states such as the state economic competitive index, state business competitive index, index of state policy environment for entrepreneurs, and index of state economic structure (Atkinson and Andes 2008; Laffer, Moore, and Williams 2009; CNBC 2010). The Tax Foundation also created a State Business Tax Climate Index (SBTCI) to measure the competitiveness of state tax systems (Padgitt 2010). Studies reveal that employment growth and business location decisions are correlated with tax rates (Bartik 1985; Mark et al. 2000). In addition, research reveals that several business climate indices can predict state-level economic growth and the SBTCI explains growth consistently (Bittlingmayer et al. 2005; Anderson and Sallee 2006). These indices have drawn much attention and have been used by businesses, government, and researchers (Anderson and Sallee 2006; Meyer

1995). However, no one has examined state woody biomass policies in terms of their strength and attractiveness for new bioenergy projects.

The purpose of this paper is to create an index from which to rank the states based on the strength of their policy incentives. This study first reviews state policies relevant to woody biomass by categories of incentives and supports. An index is then created through scoring each statute and weighting different categories and sub-categories of policies. Discussions of the state ranking and the strength of policy incentives for each individual state follow. The final section concludes this study.

Literature Review

Though some federal and state legislation has included trees and wood as feedstock for renewable energy since the 1970s, agricultural crops were the main focus of the early legislation. Since 2000 most federal forest biomass policies and programs were enacted to address the need for diversifying renewable energy sources and maintaining forest health. State governments have also played an increasing role in forest biomass utilization. Individual states have included woody biomass in a range of renewable energy incentives, regulations, and programs.

Studies and websites report detailed information on state and local renewable energy policies (NCSC et al. 2006; IREC 2009). Most states provide various tax incentives, such as property or sales tax exemptions, corporate or personal tax credits, and excise tax incentives. Many offer various loan or grant programs, and a lot of states have enacted some categories of rules and regulations. However, not all of these stipulations and programs relate to forest biomass.

Based on the Database of State Incentives for Renewable Energy (DSIRE), the Reuters FindLaw search engine, and contacts with state agency and local organizations, Becker and Lee (2008) established a woody biomass policy database that reviews the legislation and programs for each state. They categorized the policies into five broad types: tax incentives, subsidies and grants, rules and regulations, education and consultation, and financing and contracting. Although most of these renewable energy policies are not specific to woody biomass, all provide incentives relevant to forest biomass removal, transportation, and utilization.

Policies that provide non-financial incentives are more widely used by states. According to the database (Becker and Lee 2008), most states have enacted rules and regulations that require increased use of renewable energy or set up efficiency standards for biomass processing equipment. They include net metering, interconnection standards, building standards, and renewable generation requirements. Currently, 37 states have net metering programs, which provide retail credit to consumers for a portion of renewable energy generated by their own facilities. However, this rule may differ by state in terms of the worth of the credit and the period consumers can keep it. The purposes of building standards are to reduce non-renewable energy purchases and increase overall energy savings. For example, Executive Order 48 of Virginia requires the state government to implement the State Buildings Energy Reduction Plan. It also encourages private sectors to adopt this standard.

Education and consultation are also non-financial incentives that are mostly provided by state government to support woody biomass. Thirty-four states have established service provision and/or training programs to offer education courses, technical information, and business planning assistance. The Tennessee Energy Division, for example, includes the wood products industries in the successful Department of Energy (DOE) Industries of the Future Program (Becker and Lee 2008). This program identifies the most beneficial new technologies for energy saving, and waste reduction and disseminates findings and operation techniques through workshops and training programs.

Compared to rules and regulations, financial incentives are used less by states as a tool to encourage the use of forest biomass for bioenergy. Some states grant financial incentives such as renewable energy tax credit, tax deduction or exemption, and various energy loan programs (Becker and Lee 2008). Specifically, Alabama enacted a statute allowing for a tax deduction for the conversion of an existing gas or electricity system to a wood-burning heating system. South Carolina provided a biomass energy tax credit to taxpayers for the purchase and installation of energy equipment using a fuel containing at least 90% biomass resources. Biomass in this code refers to noncommercial wood, by-products of wood processing, demolition debris containing wood, and other organic materials excluding fossil fuels. Mississippi offers loans at an interest rate of 3% below the prime rate for renewable energy and energy efficiency projects using biomass and other renewable energy sources.

Some states have also provided subsidies and grants to support product commercialization and marketing (Becker and Lee 2008). For example, Alabama established Biomass Energy Programs to spur the use of woody biomass for energy. Approved projects can receive up to $75,000 for interest payments on loans. The Energy Freedom and Rural Development Act of South Carolina offered a production incentive to eligible bioenergy facilities. Qualified systems can obtain $.01 per kilowatt-hour (kWh) for electricity generated and $.30 per therm (100,000 Btu) for energy produced from biomass resources. Nonetheless, this type of financial incentive is implemented in relatively fewer states.

Due to different concerns and resource endowments, the types and numbers of the policies in each state also vary (Table 2.1). Two of the most aggressive states in stimulating renewable fuels using alternative energy sources are Massachusetts and North Carolina. They have adopted the largest number of woody biomass relevant policies and offer various financial incentives, regulations, and education and consultation supports. Comparatively, other states either have fewer or no monetary stimulations or lack regulation and/or information service. These differences indicate that the strength of government support for forest biomass utilization in each state varies substantially. The variation in state incentives will undoubtedly influence the siting decision of new biomass industry. However, little information exists on the comparison of state legislation and programs for the plant location feasibilities.

Policy Ranking Methods

In order to compare the incentives provided by individual state governments, an index approach was used to rank each state in state policies relevant to woody biomass utilization. Many economic competitiveness indices assess state economic performance or state economic structure through scoring and weighting various quantifiable indicators such as employment in different industry, investment, the number and value of initial public stock offerings by companies, the number of scientists and engineers in the workforce, gross product growth, and the number of patents issued (Atkinson and Andes 2008; Laffer, Moore, and Williams 2009). State environment and tax policy rankings also used measurable indictors such as per capita environment spending, corporate and personal income tax rate, and property tax rate, which are easy to score and compare (Ridley 1987; Padgitt 2010). Indices that included regulations as indicators used the count of policies as a measure for ranking (Hall and Kerr 1991; Reed 2009). Regarding the weighting of different indicators, many used equal-weighting method, whereas others used unequal-weighting based on their relative importance or differences in standard deviations among indicators.

Similar to the 2008 state new economy index (Atkinson and Andes 2008; Reed 2009), which weighted indicators based on their relative importance, this paper weighted each category and sub-category of woody biomass statutes based on the importance from the viewpoint of a bioenergy plant investor. Table 2.2 explains how the policies are categorized and weighted. Due to the large amount of funds needed for building a new facility and starting production, financial incentives are more attractive to new businesses. Therefore, they were given the highest weight among all legislation and programs. Since tax incentives are more important for individual project investors, they were assigned an even higher weight of 35%, whereas the other two fiscal support, subsidies and grants, and financing programs, were weighted equally at 20%. Non-financial incentives such as rules and regulations, and education and consultation, were given the lower and the lowest weight of 15% and 10%, respectively. More explanation is provided below in the description of each category.

To measure the magnitude of differences between statutes, each state woody biomass policy was scored from the vantage point of renewable energy investment. The details regarding how to score each statute were described in each category of policies. The maximum points an individual state could receive for each category of policy were calculated by multiplying the weight by 40, the maximum total points for all five categories. This meant that the maximum score for tax incentives was 14, 8 for both subsidies and grants and financing programs, and 6 and 4 for non-financial legislations rules and regulations, and education and consultation, respectively (Table 2.2). The total scores of an individual state for a policy category were then adjusted using the ratio of the maximum total points to the highest total score.

The state woody biomass policy index was then calculated by adding the states' adjusted scores in each of the five categories of woody biomass relevant policies. The simple formula for the index is defined as below:

$$I_n = \sum_{i=1}^{5} \frac{X_{in}}{\max\{X_{in}\}} \cdot P_i^{\max}$$

where I_n is the total score received by the n^{th} state. X_{in} indicates the n^{th} state's score for the i^{th} category of policies. $\max\{X_{in}\}$ is the highest score received for the i^{th} category of policies among all 50 states. $P_i^{\max}$ denotes the maximum points for the i^{th} category of policies based on its weight.

Data for the index construction were obtained from the database of the state woody biomass utilization policies built by Becker and Lee (2008). Detailed information needed for ranking was obtained from the websites of the particular state legislation and programs.

Tax Incentives

Tax incentives included two sub-categories of statutes: property and production tax credit, and deduction or exemption from the state property tax. Since a deduction or exemption merely decreases the taxable property or income, the corresponding reduction in tax owned is only a fraction of the magnitude of the deduction or exemption. Thus, a tax credit is generally regarded as more beneficial to a new plant investor. In this regard, the tax credit incentives were given higher scores than deduction and exemption policies for ranking. Property taxes are a significant determinant of business location decisions and associated with employment growth (Bartik 1985; Mark et al. 2000). The statutes that allow the qualified corporation to receive a tax credit of 50% of the property cost (or the system and installation cost) were considered as the most valuable incentives for a new renewable facility among all state tax legislations in scoring. Both were assigned a full score of six points. The scores for a tax credit of lower percentage of property cost were deducted appropriately. For example, South Carolina allows taxpayers a tax credit of 25% of equipment and installation costs; it received a score of 4. Some states do not set a specific percentage; they were given a score of mode for tax credits (two points). The exemption of the total device and installation costs from the payable tax obtained the maximum score of three points for the sub-category of the deduction or exemption program. The deduction of merely the installation cost was given a score of two points. The scores for a deduction of the device or installation costs were decreased proportionally.

Production, sales, and market policies are closely relevant to new bioenergy business. Considering a large amount of funds needed for purchasing the device and constructing a new plant, they were viewed as less important than a property incentive and arbitrarily given a score of two. Residential policies and incentives for retailers and alternative fuel vehicles (AFVs) are of relatively less importance for new business or economic growth. However, they reflect a state's general tax climate on the use of biomass feedstock. Therefore, they were scored as one. The scores of statutes with more than one incentive were the sum of the score of each incentive. The description of and score for each statute are provided in Table 2.3. The total score of each state for this category of policy was the sum of the scores of the state's statutes. States that currently have no woody biomass relevant tax incentives received a score of zero.

Subsidies and Grants

This category of policies provides grants or subsidies to spur the development of certain renewable technologies and use of alternative fuel sources. They can also be sub-categorized as grants for new projects, production incentives, funding for small bioenergy systems, research funds, and resource and information support for ranking purpose. Due to the difficulties in scoring the statutes by the maximum amount of funds that the state government offers to a qualified project, subsidies and grants were scored generally based on sub-categories in view of the birth of new industry. The incentives for new projects or installation of bioenergy facilities were given the highest score of three points. Policies of production payment and incentives for small bioenergy systems or distributed generation facilities were equally given a lower score of two points considering their less importance or a smaller amount of fund granted to an individual project. Research funds and incentives for bioenergy systems in retailers, institutions, or government were assigned the lowest score of one point, due to the same reason discussed before regarding the tax incentives. The grant programs that provide resource or information support as well as the rebates for building permit fees are not the direct financial incentives for establishing a new plant. Thus, they also received a lowest score of one point. The description and score of each statute are presented in Table 2.4. The total score for each state was calculated the same way as the category of tax incentives. States with no subsidy or grant programs received a score of zero.

Financing

The financing incentives include zero- or low-interest loans to eligible energy projects (see Table 2.5). Based on the interest rate and whether it is available for a new renewable energy project, incentives were compared and assigned a score. Programs that offer 50% of a loan at 0% interest rate or provide a loan at the low interest rate of 1%, received the highest score of five points. Scores for policies involving higher interest rates were deducted proportionally. For example, the South Carolina Renewable Energy Revolving Loan Program provides a 3%-interest-rate loan to renewable energy production facility and was given a score of three points. Programs with case-specific or undocumented interest rates were assigned a score of two and one, respectively. Programs for local government, schools, or existing business were assigned the lowest score of one point because they are not directly related to the establishment of a new plant. Many states currently have no financing incentives for woody biomass, such as Alabama, Arkansas, and Florida. Therefore, they received a zero.

Rules and Regulations

Rules and regulations enacted by state government include net metering, interconnection standards, renewable generation requirement, and building codes etc. They are mainly non-financial incentives for new plant investors. These legislations established goals and requirements for renewable energy and use of biomass. They also offer credits of renewable energy production, though they may not provide direct and strong monetary benefits to the new renewable projects as financial support. Due to the difficulties in specifying benefits for each statute, the states were ranked by the number of statutes for this category rather than comparing the monetary payments business investors can receive. The score for each state was equal to the count of woody biomass relevant statutes (Table 2.6). Wisconsin has the most statutes among the 50 states. Consequently, it received the highest point score, six. Some states (e.g. Alabama, South Carolina, and Tennessee) currently have no woody biomass relevant rules and regulations and received a score of zero.

Education and Consultation

Education and consultation policies provide technical information and business planning assistance through various workshops and training programs. Most states offer these services, but the numbers of statutes in each state vary. This at least partially reflects the extent and strength of state government support for woody biomass. Therefore, each state was ranked by the count of policies for this category of incentives.

The score of each state was exactly the number of statutes it enacted (Table 2.7). The state with the highest number of education and consultation programs is Missouri. It has enacted five policies and, thus, was given a score of five points. States that have not offered these types of services received a score of zero.

Rankings

Through summing the adjusted scores of all the five policy categories for each state, we obtained the overall woody biomass policy index for the 50 states. The total scores and rankings are presented in Table 2.8. Results indicate that Iowa and North Carolina ranked first and second among all 50 states because of their strong financial incentives and moderate levels of regulations and consultation support. Also, both states possess all policy categories relevant to woody biomass utilization. Washington was ranked third. The financial supports such as tax incentives and financing supports provided in this state are the strongest. However, education and consultation programs are still needed to compete with the Iowa and North Carolina.

Five states, Wyoming, Mississippi, Virginia, Louisiana, and Arkansas were ranked at the bottom of the index, with scores 15 points lower than the fifth place. They have very weak or even no financial incentives to the new bioenergy industry. The rules and regulations implemented and education and consultation supports are not strong, either.

Sensitivity Analysis

Considering the arbitrary weights used for total score calculation, two other weighting methods were employed to assess index sensitivity to changes in category weights. One method is equal-weighting, which has been used in many indices due to its simplicity (Arend and Bruns 2007; BHI 2009; Laffer, Moore, and Williams 2009). In this study, five categories of policies were equally weighted at 20% with a maximum value ($P_i^{\max}$) of eight points. The other method is weighting based on the variability of the 50 state scores (Padgitt 2011). The standard deviations of the scores for the five categories of policies were calculated and the weights then computed through dividing each category's standard deviation by their summation. The category of tax incentives with the greatest variability was given the largest weight of 29.3% (with a maximum value of 11.7 points). The category of rules and regulations exhibited the least variability and was assigned the smallest weight of 11.4% with a maximum value ($P_i^{\max}$) of 4.5 points. The weights for other three categories were 25.8%, 16.3%, and 17.2%, respectively. Their maximum values were 10.3, 6.5, and 6.9 points, accordingly. The indices and rankings are presented in Table 2.9. Also, the states were ranked based on the number of woody biomass policies and programs they enacted for the purpose of comparison.

Wilcoxon signed-rank test was used to compare the four indices. The null hypothesis of this test is that the median difference between pairs of indices is zero

(McDonald 2009). Results indicate that the index based on the arbitrary weights for siting new bioenergy pants was significantly different from the index of number of policies at 0.01 level. It was also different from the index created with the same category weights at 0.05 level. Its difference from the index with the variability weights was not significant. Friedman test results rejected the null hypothesis at 0.01 level that rankings using different methods are similar. However, the Wilcoxon signed-rank test indicated that state rankings based on arbitrary weights were not significantly different from ranking using other methods at the 0.1 level. This suggests that the rankings of the states will not vary significantly as category weights changes.

Correlation Analysis

These state woody biomass policies provide a variety of incentives and supports for encouraging the new bioenergy industry and woody biomass utilization. The competitiveness of these policies for new business creates a general investment climate together with other policies such as environmental regulation and tax policies in each state. To explore the potential relationship of woody biomass policies with other policies and factors, correlation tests of this index were conducted with other indices and factors such as gross domestic product (GDP) per capita and greenhouse gas (GHG) emissions were performed. Pearson's correlation coefficients between ranks are presented in Table 2.10.

The Green Index compiled by Hall and Kerr (1991) ranked each state's environmental health with a set of 256 indicators, including 67 state policies. The higher the score, the worse a state's environmental condition is. The woody biomass policy index was negatively correlated with those of the Green Index. The correlation was not large (with a coefficient of -0.4846) but significant at the 99.5% level. This result suggests that a state with better environmental health and stronger policies also provided more incentives for new bioenergy industry and woody biomass utilization.

The SBTCI ranked each state's tax systems in terms of competitiveness in attracting new business and effectiveness for economic and employment growth - the higher the score, the better a state's tax climate (Padgitt 2010). Though the tax policies received the highest weight for the woody biomass policy index, its correlation with the SBTCI was weak (with a coefficient of -0.2231) and insignificant at the 10% level. The possible reason could be that other fiscal and non-fiscal woody biomass policies together outweigh the tax incentives. The correlation coefficient of the tax climate index and the woody biomass policy index was negative probably because of the difference between these two indices. The tax climate index punishes those states offering tax credits because this incentive narrows the tax base, distort the free market, and ineffective for the long term. The woody biomass policy index, however, greatly rewarded the states providing tax credits with highest category weights and higher scores because this incentive supports the new business and woody biomass utilization at least in the short-run.

The correlations of the woody biomass index with the GDP per capita and GHG emissions were weak and insignificant (Table 10), suggesting that a state's financial condition and GHG (or energy) emission did not influence the legislation of state woody biomass policies and programs.

Discussion

Results indicated a large distinction in the government support for woody biomass utilization between the top and bottom states in policy ranking. The difference in total scores was almost 20 points between the highest and lowest states. This suggested the large disparity in competitiveness among states and the necessity of comparing these policies when determining mill location. Also, no regional similarities existed in the rankings as suggested by Reed's (2008) Environmental and Renewable Energy Innovation Potential study (Figure 2.1). This distinction could probably be explained by the variation in forest resources and the attitudes of state and local government agencies. The highest score on the index was 21.4 and its difference between the total score of 40 was large. It implied that, as with low ranking states, even the top states can improve their bioenergy business investment climate.

This study ranked the strength of state government supports on woody biomass utilization through scoring each statute and weighting different categories of incentives based on their importance in view of new plant investors. The operationalization of the policy index for this analysis was not new or complicated (Reed 2009; Ruger and Sorens

2009). According to sensitivity analysis, changes in category weights did not affect state rankings significantly. This implies that the strength of each statute and the number of policies and programs are the main determinants of a state's ranking.

Scoring each fiscal statute according to the monetary benefits provided was extremely difficult because the financial gain of a new project from a specific legislation depends on many factors such as the scale of investment, processing procedure, products manufactured, and the amount produced. For the purpose of simplification, this analysis scored the tax policies based on the general type of tax credit and exemption or deduction. The subsidy and grant programs are scored generally based on whether they fund the installation of new facilities and the production capacity of qualified projects. Therefore, siting decisions must examine and compare these fiscal policies among the states closely, based on the specific needs of their specific interests.

The state legislation used to create the ranking was obtained through the woody biomass policy database reported by Becker and Lee (2008). According to the authors, all statutes in the database provide incentives relevant to forest biomass removal or forest products utilization. Nonetheless, most of these policies foster the production and sale of renewable energy and alternative fuels. In addition to woody biomass, a variety of other sources can be used as their feedstocks such as crops, agricultural residues, and wastes. The choice of sources will depend on the technology used and various costs associated with biomass procurement. Previous studies have reported the barriers facing forest biomass utilization such as the costs of harvesting and transportation and technology constraints (Guo 2007). To address these challenges, state policies specific to woody biomass may provide more incentives (e.g. healthy forest enterprise incentives program, A.R.S. § 41-1516) than general legislation for renewable energy (e.g. renewable energy production tax credit, HB 7134). This policy index did not take this factor into consideration because of the difficulty in quantifying the strength of each statute on woody biomass relative to other biomass types.

Conclusion

This research analyzed the disparity in the strength of state government incentives from the viewpoint of bioenergy investment and woody biomass utilization. State supports were compared through evaluating and ranking their fiscal and non-fiscal statutes and programs relevant to forest biomass removal and forest production utilization. The index approach has long been used for ranking the environment quality and government policies and efforts (Ridley 1987; Brown et al. 1990; List and Mchone 2000). This study is the first that applies the approach to investigate the legislation related to forest biomass.

Results identified the strongest and weakest states in terms of woody biomass policies. Iowa, North Carolina, and Washington were ranked at the top in spurring the use of this new source for energy. They attract new projects through the most beneficial tax incentives together with other financial support and technology and consultation assistance. Comparatively, the lowest ranked states need more fiscal policies if they wish to attract the forest biomass industry.

The policy index created by this study is valuable in the following respects. First, it is very helpful for project directors in screening states for siting decisions. The main reason is that the statutes cover many aspects of project planning such as market demand, capital appropriation, and legal environment. All of these factors are especially important for business investment. Second, state legislators and local policy makers can determine the relative strength of their states and determine what policies may foster the use of forest resources for renewable energy production. Moreover, researchers may also use this index to model the set up of new industry as policy outcomes and other associated economic and environment development in the U.S.

It must be noted that the data used for this analysis is mainly from the state woody biomass policy database developed in 2008 (Becker and Lee 2008). State regulations and programs implemented later were not included in this investigation. Therefore, the data of post-2008 state policy changes may be needed for future comparison and decision-making for a new project.

APPENDIX: TABLES AND FIGURES

Table 2.1 The summary of the number of policies by category in each state.

State	Tax Incentives	Subsidies and Grants	Rules and Regulations	Education and Consultation	Financing and Contracting
Alabama	1	1		3	
Alaska	1	1	1	0	0
Arkansas			3	1	
Arizona	2	1	0	3	0
California	3	5	2	2	1
Colorado	2	3	0	2	3
Connecticut	2	3	1	5	2
Delaware	0	2	0	2	0
Florida	2	4	0	1	3
Georgia	3	0	0	0	1
Hawaii	1	1	1	5	1
Idaho	3	3	1	1	1
Illinois	1	2	1	3	0
Indiana	0	1	0	1	0
Iowa	4	1	3	3	1
Kansas	4	0	0	0	1
Kentucky	3	0	0	2	0
Louisiana	0	0	0	2	2
Maine	1	2	0	3	0
Maryland	3	0	0	2	0
Massachusetts	2	4	2	5	2
Michigan	2	2	0	2	1
Minnesota	1	2	1	5	0
Mississippi	0	0	1	1	0
Missouri	1	1	1	4	5
Montana	9	1	0	1	0
Nebraska	0	0	1	1	0

Table 2.1 Continued

State	Tax Incentives	Subsidies and Grants	Rules and Regulations	Education and Consultation	Financing and Contracting
Nevada	2	0	0	4	1
New Hampshire	1	2	1	2	1
New Jersey	0	1	0	6	0
New Mexico	5	0	0	1	2
New York	1	1	0	7	1
North Carolina	3	4	1	3	4
North Dakota	3	1	0	6	2
Ohio	3	2	0	6	4
Oklahoma	0	0	2	2	1
Oregon	4	2	1	3	3
Pennsylvania	0	3	0	3	1
Rhode Island	1	1	0	3	1
South Carolina	1	2	1	0	2
South Dakota	1	1	0	2	2
Tennessee	0	0	1	0	4
Texas	2	0	0	6	3
Utah	3	0	0	2	1
Vermont	2	2	1	1	2
Virginia	0	0	0	4	0
Washington	8	2	1	2	0
West Virginia	0	0	0	1	3
Wisconsin	0	5	0	8	1
Wyoming	1	0	0	1	0

Source: the Database of State Incentives for Renewable Energy (DSIRE) (IREC 2009).

Table 2.2 State woody biomass policy categories and their weights.

Categories	**Measurement**	**Weight**	**Maximum Points**
Financial Incentives			
Tax Incentives	Financial benefits to new facility investors	35%	14
Subsidies and Grants	Financial benefits to new facility investors	20%	8
Financing and Contracting	Financial benefits to new facility investors	20%	8
Non-financial Incentives			
Rules and Regulations	Count of statutes	15%	6
Education and Consultation	Count of statutes	10%	4
	Total	100%	40

Table 2.3 State Tax Incentives Relevant to Woody Biomass Utilization

State	Tax Incentives	Description	Score	Total
Alabama	Wood Burning Heating System Deduction (1999)	Deduction; Residential; Total cost of installation	1	1
Alaska	Sustainable Natural Alternative Power Program (2003)	Credit; Commercial; Residential; $/kWh	2	2
Arizona	Property Tax Assessment for Renewable Energy Property (2008)	Certified business; assessed at 20% of its depreciated cost	2	7
	Healthy Forest Enterprise Incentives Program (2005)	New Job Income Tax Credit; Deduction of use fuel tax and property tax; use tax Exemption; Certified business	5	
Arkansas			0	0
California	Supplemental Energy Payments (2007)	Rebate; above market costs of procurement	2	6
	Personal Income Tax Law and the Corporation Tax Law (2006)	Deduction for depreciation	2	
	Sales and Use Tax Law (2007)	Exemption for fuel transporting biomass	2	
Colorado	Local Option – Property Tax Exemption for Renewable Energy Systems (2007)	Property or sales tax rebates or credits	2	4
	Local Option – Sales Tax Exemption for Renewable Energy Systems (2007)	Sales tax rebates or credits	2	
Connecticut	Connecticut Clean Energy Fund (1998)	Rebates	2	3
	Property Tax Exemption for Renewable Energy (2007)	Exemption; residential	1	
Delaware			0	0
Florida	Renewable Energy Production Tax Credit (2006)	Credit; Commercial; $0.01/kWh	2	5
	Renewable Energy Property Tax Exemption (2008)	Exemption; Residential; Device and installation cost	3	
Georgia	Biomass Sales and Use Tax Exemption (2006)	Exemption; Commercial/Residential; Biomass	2	8
	Corporate Clean Energy Tax Credit (2008)	Credit; Commercial/Multi-residential; 35% system & installation cost	5	
	Alternative Fuel Production Facility Tax Exemption (2006)	Exemption; Individual; personal property for construct	1	
Hawaii	High Technology Business Investment Tax Credit （2003）	100% credit on equity investment in qualified high tech business	6	6
Idaho	Residential Alternative Energy Tax Deduction （2007）	Deduction of 40% of device cost (max. $5000); Residential	1	5
	Renewable Energy Equipment Sales Tax Refund （2005）	Sales-and-use tax rebate; Commercial/residential	2	
	Biofuel Fueling Infrastructure Tax Credit （2007）	Credit; 6% of investment (not exceed 50% of liability)	2	
Illinois	Biodiesel Production Tax (2007)	Tax exemption; Energy producers	2	2
Indiana			0	0

Table 2.3 Continued

State	Tax Incentives	Description	Score	Total
Iowa	Renewable Energy Production Tax Credit (Corporate) （2005）	Credit; Commercial; $0.015/kWh	2	10
	Renewable Energy Production Tax Credit (Personal) （2008）	Credit; Commercial; $0.015/kWh	1	
	Energy Replacement Generation Tax Exemption （2001）	Exemption; Commercial/residential; $0.0006/kWh	2	
	Alternative Fuel Production Tax Credits (2003)	Credit; Exemption of 100% of value added to property	5	
Kansas	Renewable Energy Property Tax Exemption （1999）	Exemption of property tax	3	9.5
	Biomass-to-Energy Plant Tax Credit （2006）	Credit; 10%-5% of investment; Deduction; 55% of facility cost	4.5	
	Renewable Fuel Retailer Incentive (2008)	Credit; $0.065-0.03/gal; retailer	1	
	Alternative Fuel Vehicle (AFV) Tax Credit (2005)	Credit; up to 40% of incremental or conversion cost for qualified AFVs	1	
Kentucky	Tax Credit for Renewable Energy Facilities (2007)	Credit; Commercial; 100% income, limited liability, sales tax	5	10
	Sales Tax Exemption for Large-Scale Renewable Energy Projects(2007)	Exemption; Commercial; 100% income, limited liability, sales tax		
	Alternative Fuel Production Tax Incentives (2008)	Credit; Commercial; 100% income, limited liability, sales tax	5	
Louisiana			0	0
Maine	Biofuels Production Tax Credit (2004)	Credit; $0.05/gal; producer	2	2
Maryland	Clean Energy Production Tax Credit (Corporate) (2000)	Credit; $0.0085-0.005/kWh; Commercial/residential	2	4
	Clean Energy Production Tax Credit (Personal) (2000)	Credit; $0.0085-0.005/kWh; Commercial/residential	1	
	Wood Heating Fuel Exemption	Exemption of sales tax; residential	1	
Massachusetts	Alternative Energy and Energy Conservation Patent Exemption (Corporate) (1979)	Deduction for income from sale or lease; commercial	2	3
	Alternative Energy and Energy Conservation Patent Exemption (Personal) (1979)	Deduction for income from sale or lease; consumer	1	
Michigan	Renewable Payroll Credit (2002)	Credit for qualified payroll amount; commercial	2	5
	Alternative Energy Personal Property Tax Exemption (2002)	Exemption; Commercial	3	
Minnesota	Business Tax Credit	Credit; 1.9¢/kWh; Business	2	2
Mississippi			0	0
Missouri	Wood Energy Production Credit (1997)	Credit; $5.00/ton of processed material	2	2

Table 2.3 Continued

State	Tax Incentives	Description	Score	Total
Montana	Alternative Energy Investment Tax Credit (Corporate) (2001)	Credit; up to 35% against tax on income from investment	2	15
	Alternative Energy Investment Tax Credit (2001)	Credit; up to 35% against tax on income from investment		
	Alternative Energy Investment Tax Credit (Personal) (2001)	Credit; up to 35% against tax on income from investment	1	
	Property Tax Abatement for Production and Manufacturing Facilities (2007)	Deduction; assessed at 50% of taxable value	2	
	Residential Alternative Energy System Tax Credit (2001)	Credit; device and installation cost (max $500); residential	1	
	Generation Facility Corporate Tax Exemption (2001)	Exemption of property tax; Commercial; less than 1MW capacity	2	
	Corporate Property Tax Reduction for New/Expanded Generating Facilities (1981)	Reduction; Commercial; 1MW or greater capacity	2	
	Renewable Energy Systems Exemption (2005)	Exemption of property tax; Commercial/residential	3	
	Renewable Energy Property Tax Incentive (2007)	Tax rate abatements of up to 3%	2	
Nebraska			0	0
Nevada	Property Tax Abatement for Green Buildings (2007)	Deduction; 25-35% of property tax; Commercial	1	3.5
	Renewable Energy Producers Property Tax Abatement (1997)	Deduction; 50% of property tax; Commercial	2.5	
New Hampshire	Property Tax Exemption for Renewable Energy (1976)	Exemption; residential	1	1
New Jersey			0	0
New Mexico	Renewable Energy Production Tax Credit – Corporate (2002)	Credit; $0.01/kWh against corporate income tax; Commercial	2	8
	Renewable Energy Production Tax Credit (2007)	Credit; $0.01/kWh against personal income tax; Commercial	1	
	Biomass Equipment and Materials Deduction (2005)	Deduction; 5% of property value; Commercial	1	
	Alternative Energy Manufacturer's Tax Credit (2006)	Rebate; 5% of equipment or expenditures; Commercial	2	
	Biofuels Tax Exemption (2005)	Deduction of compensating tax; value of biomass; Producer	2	
New York	Solar, Wind and Biomass Systems Exemption (2002)	Exemption; Increased accessed property value; Commercial	2	2
North Carolina	Renewable Energy Tax Credit (Corporate) (1999)	Credit; Commercial; 35% equipment & installation	5	6
	Renewable Energy Tax Credit (Personal) (1977)	Credit; Commercial; equipment & installation cost not exceeding 50% of liability that year	1	
	Renewable Energy Property Tax Credit (2007)	Credit; Commercial; 35% property cost		
North Dakota	Renewable Energy Tax Credit (Corporate) (2001)	Credit; 3% of income tax; Commercial	2	5
	Renewable Energy Tax Credit (Personal) (2001)	Credit; 3% of income tax; Individual	1	
	25 X 25 Initiative (2007)	Credit	2	

Table 2.3 Continued

State	Tax Incentives	Description	Score	Total
Ohio	Energy Conversion Facilities Corporate Tax Exemption (1978)	Exemption of franchise tax; Commercial	1	6
	Energy Conversion Facilities Property Tax Exemption (1978)	Exemption of property tax; Commercial	3	
	Energy Conversion Facilities Sales Tax Exemption (1978)	Exemption of sales and use tax; Commercial	2	
Oklahoma			0	0
Oregon	Renewable Energy Systems Exemption (1976)	Exemption of property tax; Commercial/residential	3	11
	Oregon Renewable Fuels Standards (2007)	Credit; $10/green ton; producer	2	
	Tax Credit for Renewable Energy Equipment Manufacturers (2007)	Credit; 50% of construction and equipment costs; Commercial	6	
	Business Energy Tax Credit (2007)	Credit; 35% of construction and equipment costs; Other projects; Commercial		
Pennsylvania			0	0
Rhode Island	Property Tax Exemption for Renewable Energy Systems (1980)	Exemption; Residential	1	1
South Carolina	Biomass Energy Tax Credit (2007)	Credit; Industrial; 25% equipment & installation	4	4
South Dakota	Renewable Energy Systems Exemption (1975)	Exemption; Property tax; Commercial/residential	3	3
Tennessee			0	0
Texas	Renewable Diesel Tax Credit (2005)	Credit; $1 per gallon of renewable diesel	2	5
	Renewable Energy Systems Property Tax Exemption (1981)	Exemption; Commercial; property & installation	3	
Utah	Renewable Energy Systems Tax Credit (2001)	Credit; 10% of installation costs or $0.0035/kWh; Commercial/residential	2	5
	Renewable Energy Systems Tax Credit (Personal) (2001)	Credit; Commercial/residential	1	
	Renewable Energy Sales Tax Exemption (2004)	Exemption; Commercial	2	
Vermont	Local Option for Property Tax Exemption (1975)	Exemption; Total value of system; Commercial/residential	3	5
	Sales Tax Exemption (1999)	Exemption; Commercial/residential	2	
Virginia			0	0

Table 2.3 Continued

State	Tax Incentives	Description	Score	Total
Washington	Tax on Manufacturers and Processors of Timber Product Activities (2008)	Deduction; reduced tax rate of 0.138% of product value	2	15
	Exemptions – Property used to Manufacture Alcohol, Biodiesel of Wood Biomass Fuel (2008)	Exemption of property and leasehold taxes	3	
	Exemptions – Use of Machinery, Equipment, Vehicles, and Services Related to Wood (2003)	Exemption of retail sales tax	2	
	Business and Occupation Tax (2003)	Deduction; retailer	1	
	Biofuels Retail Tax Exemption (2003)	Exemption from retail fuel sales and use tax; retailers	1	
	Biofuels Tax Deduction (2003)	Deduction; Distributors and retailers	1	
	Biofuels Production Tax Exemption (1998)	Exemption of property tax; reduced B&O tax rate of 0.138%	3	
	Sales and Use Tax Exemption (2001)	Exemption; Commercial/residential	2	
West Virginia			0	0
Wisconsin			0	0
Wyoming	Renewable Energy Sales Tax Exemption (2003)	Exemption; Commercial	2	2

Table 2.4 State Subsidy and Grant Incentives Relevant to Woody Biomass Utilization

State	Subsidies and Grants	Description	Score	Total
Alabama	Biomass Energy Program (1986)	Max. individual award of $75,000 in interest subsidy payments	3	3
Alaska	Renewable Energy Grant Program (2008)	$50 million annual funding for research, design, and construction	3	3
Arizona	Renewable Incentives Program (2007)	Sell credits to APS; Receive performance based incentive	2	2
Arkansas			0	0
California	Energy: Renewable Energy Resources (2007)	Funding to reduce fuel costs	1	9
	California Feed-In Tariff (2008)	Sale of renewable electricity from small systems to utility	2	
	Public Benefits Funds for Renewables and Efficiency (2000)	Funding for production and market	2	
	Biomass Standard Contract (2007)	Production payment ($92.71-95.72/MWh)	2	
	Renewable Energy Credits (2007)	RECs associated with DG facilities	2	
Colorado	Funding for Alternative Fuel Feedstock Production (2007)	Funding for bioenergy projects	3	8
	Clean Energy Development Authority (2007)	Issue bonds to finance projects	3	
	Community Biomass for Thermal Usage Program (2007)	Grant to heating projects	2	
Connecticut	Operational Demonstration Program (2006)	Max individual award $750,000 for demonstration projects	3	7
	New Energy Technology Program (2007)	Max individual award $10,000 for renewable energy technologies (30 or fewer employees)	2	
	On-Site Renewable DG Program (2005)	Total funding: $66.24 million for installation at commercial or industrial building	2	
Delaware	Research and Development Grants (1999)	Grants up to 35% of project (max. $250,000)	3	6
	Green Energy Fund (1999)	Grants for installation	3	
Florida	Florida Farm to Fuel Grants Program (2007)	$25 million in matching grants for bioenergy projects	3	10
	Renewable Energy Technologies Grant Program (2006)	$15 million with at least $8 million for bioenergy projects	3	
	Alternative Fuels Production Incentive (2008)	Provide resources for business projects	1	
	Renewable Energy Grants (2008)	Matching grants for projects	3	
Georgia			0	0
Hawaii	Renewables and Efficiency in State Facilities and Operations (2006)	$5 million for photovoltaic, net metered pilot project in schools	1	1

Table 2.4 Continued

State	Subsidies and Grants	Description	Score	Total
Idaho	Renewable Energy Grant (2005)	BEF grant not exceed 33% of capital costs for government and nonprofits	1	5
	Biofuels Infrastructure Grant (2007)	50% of project cost; retailers	1	
	Renewable Energy Project Bond Program (2005)	Funding from Bonds for construction of projects	3	
Illinois	Biogas and Biomass to Energy Grant Program (1997)	50% cost-share for installation of on-site generation facilities	2	5
	Illinois Clean Energy Community Foundation Grants (1999)	Case-by-case award to projects	3	
Indiana	The Alternative Power and Energy Program (2006)	Cost-share grants of 879,000 for system installation	3	3
Iowa	Grants for Energy Efficiency and Renewable Energy Research (1990)	Research grants	1	1
Kansas			0	0
Kentucky			0	0
Louisiana			0	0
Maine	Voluntary Renewable Resources Grant (2000)	Individual grants of up to $50,000 for small-scale demonstration projects	2	3
	Renewable Resource Fund (1998)	Grants for research and demonstration projects for schools, institutions, etc.	1	
Maryland			0	0
Massachusetts	Clean Energy Pre-Development Financing Initiative (2005)	Grants and loans for grid-connected systems	2	9
	Large Onsite Renewables Initiative (2006)	Grants for grid-tied projects	2	
	Clean Energy Pre-Development Financing Initiative (2005)	Awards of up to $500,000 for companies in the early stage of development	3	
	Renewable Energy Trust Fund (1997)	grants, contracts, loans, equity investments, energy production credits, bill credits and rebates to customers	2	
Michigan	Biomass Energy Program Grants (2008)	Case-by-case funding for schools and institutions	1	3
	Low-Income and Energy Efficiency Fund (2000)	Awards to energy-efficiency projects (75% for low-income residents, 25% for all customers)	2	
Minnesota	Minnesota Power Grant Program	Grants up to $50,000/project	3	6
	Xcel Energy – Renewable Development Fund Grants (1999)	New development project for production ($2 million); R&D ($1 million)	3	
Mississippi			0	0
Missouri	Bio-processing Input Procurement Strategies (2005)	SERBP ($44,000); cost-share ($12,500) to biomass procurement and marketing strategy research	1	1
Montana	Renewable Energy Grant (2000)	BEF grant not exceed 33% of capital costs	1	1
Nebraska			0	0
Nevada			0	0

Table 2.4 Continued

State	Subsidies and Grants	Description	Score	Total
New Hampshire	Renewable Energy Generation Incentive Program (2008)	50% of system cost (max. $6,000) to residential owners of small facilities	2	3
	New Hampshire Bio-Oil Feasibility Study (2002)	Research funds	1	
New Jersey	Clean Energy Rebate Program (1999)	Funding for renewable energy systems	3	3
New Maxico			0	0
New York	High-Efficiency Biomass Heating Technologies (2008)	Research funds ($1.6 million, with an additional $0.9 million in co-funding from research partners)	1	1
North Carolina	Local Option Green Building Initiative (2007)	Reductions or partial rebates for building permit fees	1	7
	Biomass Market Development for North Carolina (2005)	Biomass waste exchange website ($48000; cost share $10000), consulation	1	
	North Carolina Green Business Fund (2007)	$100,000 for commercial innovations and application	3	
	NC Green Power Production Incentive (2003)	Offers production payments	2	
North Dakota	Feasibility Study of a Biomass Supply for the Spiritwood Industrial Park (2008)	Research funds ($109,000)	1	1
Ohio	Advanced Energy Program Grants – Distributed Energy and Renewable Energy	25% of project cost (max. $100,000)	2	5
	Advanced Energy Fund (1999)	Grants for renewable energy projects	3	
Oklahoma			0	0
Oregon	Renewable Energy Grant (2000)	BEF grant not exceed 33% of capital costs for government and nonprofits	1	4
	Energy Trust – Open Solicitation Program (2002)	$2 million annually to fund projects	3	9
Pennsylvania	Pennsylvania Energy Development Authority – Grants (1982)	Grants for projects ($11 million in 2008)	3	
	Pennsylvania Energy Harvest Grant Program (2003)	Grants for bioenergy projects, etc. (avg. $200,000)	3	
	Renewable Energy Grants (2007)	Grants and loan guarantees for biomass involved projects	3	
Rhode Island	Rhode Island Renewable Energy Fund (1996)	$2.4 million for renewable energy and DSM programs	3	3
South Carolina	Biomass Energy Production Incentive (2007)	$.01 per KWH and $.30 per therm (100,000 Btu)	2	5
	Renewable Energy Grant Program (2007)	$200,000 for demonstration projects (max. 50% of total cost)	3	
South Dakota	Energy Efficient Government Biomass Study (2006)	Research funds	1	1
Tennessee			0	0
Texas			0	0
Utah			0	0
Vermont	Biomass Electricity Production Incentive (2004)	Purchase credits at 95% of price + $0.04/kWh	2	3
	Clean Energy Development Fund Grant Program (2005)	$1.7 million (closed)	1	
Virginia			0	0

Table 2.4 Contiuned

State	Subsidies and Grants	Description	Score	Total
Washington	Sustainable Natural Alternative Power Program (2004)	max. $1.00/kWh for renewable energy generators	2	3
	Renewable Energy Grant (2000)	BEF grant not exceed 33% of capital costs for government and nonprofits	1	
West Virginia			0	0
Wisconsin	Focus on Energy – Renewable Energy Cash-Back Rewards (2007)	Cash-back rewards based on estimated annual production for installing or expanding systems	3	9
	Energy Independence Fund Grant and Loan Program (2006)	Grants: 50% cost-share; loans: 4% interest rate, max. 25% of project cost	3	
	Focus on Energy – Renewable Energy Grant Programs (2007)	Grants for business and marketing, etc.	2	
	Direct Financial Incentives for Not-for-Profits (2008)	50% installation cost ($10,000-$100,000) for nonprofits	1	
	GLBSRP Grants	Grants (ended)		
Wyoming			0	0

Table 2.5 State Financing and Contracting Incentives Relevant to Woody Biomass Utilization

State	Financing and Contracting	Description	Score	Total
Alabama			0	0
Alaska	Project Power Loan Program (1999)	Loan interest rates are the lesser of average weekly yield of municipal bonds	2	2
Arizona			0	0
Arkansas			0	0
California	Loans for Energy Efficiency Projects (2007)	Loan (3.98%, max. $3 million)	2	2
Colorado			0	0
Connecticut	Energy Conservation Loan (2006)	Loan interest rates based on family size and income	1	1
Delaware			0	0
Florida			0	0
Georgia			0	0
Hawaii	Farm and Aquaculture Sustainable Projects Loan (2008)	Loan (85% of project cost, max. $1,500,000); 3% for agriculture	3	3
Idaho	Low-Interest Energy Loan Program (2003)	Low-Interest Loan ($1,000 - $100,000)	2	2
Illinois	Renewable Energy Resources Trust Fund (1997)	Grants, loans, and other incentives	3	3
Indiana			0	0
Iowa	Alternative Energy Revolving Loan Program (1996)	50% of loan at 0% interest	5	11
	Iowa Energy Bank (2008)	Loan to schools and governments	1	
	Alternative Fuel Loan Program (1996)	0% interest; half of biomass or fuel costs (max. $1 million)	5	
Kansas			0	0
Kentucky			0	0
Louisiana			0	0
Maine			0	0
Maryland			0	0
Massachusetts	Business Expansion Initiative (2007)	Loan	1	2
	Sustainable Energy Economic Development Initiative (2004)	Loan (max. $500,000)	1	
Michigan			0	0
Minnesota	Energy Investment Loan Program (2001)	Loan 50% of project cost (max. $500,000) to school, government	1	1
Mississippi	Energy Investment Loan Program (1989)	Low-interest loans (3% below prime rate) $15000-300,000	3	3
Missouri	Energy Loan Program (1989)	Loan interest loans to school, government	1	1
Montana			0	0
Nebraska	Dollar and Energy Savings Loan (2006)	Low-interest loans	2	2
Nevada			0	0
New Hampshire	Renewable Energy and Energy Efficiency Business Loan (2006)	Low-interest loans	2	2
New Jersey			0	0

Table 2.5 Continued

State	Financing and Contracting	Description	Score	Total
New Mexico			0	0
New York			0	0
North Carolina	Energy Improvement Loan Program (2001)	Low-interest loans: 1% for renewable energy projects; 3% for energy efficiency projects	5	5
North Dakota			0	0
Ohio			0	0
Oklahoma	Community Energy Education Management Program (2007)	Revolving loan (3%) for local government (no more than $150,000)	1	2
	Energy Loan Fund for Schools (2007)	Loan (3%) for schools (no more than $200,000)	1	
Oregon	Small-Scale Energy Loan Program (1980)	Low-interest loans ($20,000 - $20 million)	2	2
Pennsylvania			0	0
Rhode Island			0	0
South Carolina	Renewable Energy Revolving Loan Program (2007)	Loan (3% for 2008) for renewable energy production facility (not exceed $250,000)	3	3
South Dakota			0	0
Tennessee	Small Business Energy Loan Program (1987)	Loan (0% in 3-star community, 3% others) not for new business	2	2
Texas			0	0
Utah			0	0
Vermont	Clean Energy Development Fund Loan Program (2005)	4% interest rate loan ($50,000- $250,000)	2	2
Virginia			0	0
Washington	Alternative Fuel Grant and Loan Program (2008)	Low-interest loans and grants (up to $50,000 per project)	3	3
West Virginia			0	0
Wisconsin			0	0
Wyoming			0	0

Table 2.6 State Rules and Regulations Relevant to Woody Biomass Utilization

State	Rules and Regulations	Score
Alabama		0
Alaska		0
Arizona	Renewable Portfolio Standard (2006)	3
	Arizona Net Metering (2004)	
	Renewable Energy Credit Purchase Program (2004)	
Arkansas	Arkansas Net Metering (2007)	3
	Green Building Standards for State Facilities (2005)	
	Interconnection Standards (2007)	
California	Renewable Energy Portfolio (2003)	2
	State Biofuels Development Plan (2006)	
Colorado	Colorado Renewable Portfolio Standard (2006)	2
	Colorado Net Metering (2008)	
Connecticut	Project 150 Initiative (2003)	5
	Green Power Purchase Plan (2004)	
	Green Building Standards for State Facilities (2007)	
	Renewable Portfolio Standard (1998)	
	Connecticut Net Metering (2007)	
Delaware	Renewable Portfolio Standard (2008)	2
	Delaware Net Metering (2008)	
Florida	Florida Net Metering (2008)	1
Georgia		0
Hawaii	Priority Permit Processing for Green Buildings (2006)	5
	Interconnection Standards (2004)	
	Renewable Portfolio Standard (2003)	
	Hawaii Net Metering (2001)	
	Biofuels Production Land Use Allowance (2008)	
Idaho	Idaho Net Metering (1997)	1

Table 2.6 Continued

State	Rules and Regulations	Score
Illinois	Green Power Purchasing (2007) Renewable Portfolio Standard (2007) Illinois Net Metering (2007)	3
Indiana	Energy Efficient State Building Initiative (2008)	1
Iowa	Mandatory Utility Green Power Option (2004) Alternative Energy Law (2007) Iowa Net Metering (1984)	3
Kansas		0
Kentucky	Kentucky Net Metering (2008) State Energy Plan Alternative Fuel Requirements (2008)	2
Louisiana	Renewable Fuels Standard (2006) Louisiana Net Metering (2003)	2
Maine	Renewable Portfolio Standards (1999) Maine Net Metering (1998) Governor's Wood-to-Energy Initiative (2008)	3
Maryland	Renewable Energy Portfolio Standard (2004) Maryland Net Metering (1997)	2
Massachusetts	Green Power Purchasing Commitment (2007) Energy Reduction Plan for State Buildings (2007) Renewable Portfolio Standard (1997) Massachusetts Net Metering (1997) Biodiesel Blend Mandate (2008)	5
Michigan	Renewable Portfolio Standard (2008) Michigan Net Metering (2008)	2

Table 2.6 Continued

State	Rules and Regulations	Score
Minnesota	Biomass Harvest Guidelines (2005)	5
	Environmental and Economic Incentives for Growing Hybrid Poplars to Meet Minnesota’s Demands for Biomass Products and Energy (2005)	
	Renewable Portfolio Standard (2007)	
	Minnesota Net Metering (1981)	
	Xcel Energy Wind and Biomass (1997)	
Mississippi	Biomass Program (2006)	1
Missouri	Midwest Green-E Certification (2005)	4
	Renewable Electricity Standard (2008)	
	Missouri Renewable Portfolio Standard (2009)	
	Missouri Net Metering (2007)	
Montana	Mandatory Utility Green Power Option (2003)	1
Nebraska	Nebraska Net Metering (2007)	1
Nevada	Energy and Environmental Design Requirements (2005)	4
	Fuel Mix and Emissions Disclosure (2001)	
	Energy Portfolio Standard (1997)	
	Nevada Net Metering (1997)	
New Hampshire	Renewable Portfolio Standard (2007)	2
	New Hampshire Net Metering (1998)	
New Jersey	Energy Efficiency in New School Construction (2002)	6
	High Performance Building Standards in New State Construction (2008)	
	Environmental Information Disclosure (1999)	
	Interconnection Standards (1999)	
	Renewable Portfolio Standard (1999)	
	New Jersey Net Metering (1999)	
New Mexico	New Mexico Net Metering (2007)	1

Table 2.6 Continued

State	Rules and Regulations	Score
New York	Renewable Power Procurement Policy (2001)	7
	New York Net Metering (1997)	
	Biomass Resource Program	
	Green Building Requirements for Municipal Buildings (2005)	
	Environmental Disclosure Program (1998)	
	Renewable Electricity Goal (2004)	
	Renewable Portfolio Standard (2004)	
North Carolina	Interconnection Standards (2008)	3
	Renewable Energy and Energy Efficiency Portfolio Standard (2007)	
	North Carolina Net Metering (2005)	
North Dakota	25 X 25 Initiative (2007)	6
	25 X 25 Initiative (2007)	
	25 X 25 Initiative (2007)	
	Renewable and Recycled Energy Objective (2006)	
	North Dakota Net Metering (1991)	
	Renewable Fuels Promotion (2007)	
Ohio	The Advanced Energy Technologies – Renewables and Cogeneration Program (2006)	6
	Energy Efficiency in New School Construction (2007)	
	Environmental Disclosure (1999)	
	Interconnection Standards (1999)	
	Alternative Energy Resource Standard (2008)	
	Ohio Net Metering (1999)	
Oklahoma	High Performance Building Standards in State Buildings (2008)	2
	Oklahoma Net Metering (1998)	
Oregon	Biomass Logging Bill (2005)	3
	Oregon Net Metering (1999)	
	Mandatory Utility Green Power Option (2007)	

Table 2.6 Continued

State	Rules and Regulations	Score
Pennsylvania	Alternative Energy Portfolio Standard (2004)	3
	Pennsylvania Net Metering (2006)	
	Woody Biomass Harvesting Guidelines (2008)	
Rhode Island	Green Building Standards for State Facilities (2005)	3
	Renewable Energy Standard (2004)	
	Rhode Island Net Metering (1998)	
South Carolina		0
South Dakota	High Performance Building Requirements for State Buildings (2008)	2
	Renewable and Recycled Energy Objective (2008)	
Tennessee		0
Texas	City Public Service First E85 Feet, Biomass-Derived Ethanol in Texas (2005)	6
	Alternative Energy in New State Construction (1995)	
	Fuel Mix and Emissions Disclosure (2004)	
	Interconnection Standards (1999)	
	Renewable Generation Requirement (1999)	
	Texas Net Metering (2007)	
Utah	Renewable Portfolio Goal (2008)	2
	Utah Net Metering (2002)	
Vermont	Vermont Net Metering (1998)	1
Virginia	State Buildings Energy Reduction Plan (2007)	4
	Voluntary Renewable Energy Portfolio Goal (2007)	
	Interconnection Standards (1999)	
	Virginia Net Metering (1999)	
Washington	Renewable Portfolio Standard (2006)	2
	Washington Net Metering (1998)	
West Virginia	West Virginia Net Metering (2006)	1

Table 2.6 Continued

State	Rules and Regulations	Score
Wisconsin	Wisconsin Green Power Purchasing (2006)	8
	Focus on Energy Program (1999)	
	Biomass Production Plan (2008)	
	Biomass Market Development (2008)	
	Biomass Commodity Exchange (2008)	
	Great Lakes Biomass State-Regional Partnership (1983)	
	Renewable Portfolio Standard (2006)	
	Wisconsin Net Metering (1992)	
Wyoming	Wyoming Net Metering (2001)	1

Table 2.7 State Education and Consultation Policies Relevant to Woody Biomass Utilization

State	Education and Consultation	Score
Alabama	Electric Power and Renewable Energy (2006)	
	Renewable Fuels Program (2005)	
	Biomass Program (2003)	3
Alaska		0
Arizona		0
Arkansas	Energy and Value-Added Products from Biomass (2005)	1
California	Renewable Fuels Program (2005)	1
Colorado	The Woody Biomass Program (2007)	
	Colorado Biomass Market Transformation (2005)	
	Market-Based Green Tag Program for Electricity from Forest Biomass and Coal (2003)	3
Connecticut	Renewable Energy Project (2006)	
	Connecticut Biomass Working Group (2003)	2
Delaware		0
Florida	Development of an Integrated Biomass Resource Plan and Network for Florida (2005)	
	Bioenergy Development Program (2006)	
	Biomass Project (2006)	3
Georgia	Georgia Biomass Task Force (2005)	1
Hawaii	Technology Innovation Activity (2005)	1
Idaho	Fuels for Schools (2004)	1
Illinois		0
Indiana		0
Iowa	Fostering Bio-Products Markets: Markey Conditioning for an Iowa Rebuild America Community (2005)	1
Kansas	Kansas Biomass Energy Resources Assessment (2003)	1
Kentucky		0
Louisiana	Revision, Update and Distribution of the Booklet Biomass Energy Resources in Louisiana (2005)	
	Renewable Biomass Resources Program (2008)	2
Maine		0
Maryland		0

Table 2.7 Continued

State	Education and Consultation	Score
Massachusetts	The Biomass Energy Policy and Market Development Program (2006)	
	Biofuels Incentives Study (2008)	2
Michigan	Biomass Curriculum (2003)	1
Minnesota		0
Mississippi		0
Missouri	Biomass Power Program (2006)	
	The Bioenergy and Biobased Products Program (2006)	
	Department Biomass Team (2005)	
	Biopower Decisions Tools Project (2005)	
	Renewable Energy Assessment and Outreach (2003)	5
Montana		0
Nebraska		0
Nevada	Wood Use Center (2005)	1
New Hampshire	Renewable Energy Program (2006)	1
New Jersey		0
New Mexico	Biomass Program (2005)	
	The Biomass Utilization Activity (2003)	2
New York	System Benefits Charge (1996)	1
North Carolina	Assessing Renewable Resources (2004)	
	Clean Technology Demonstration (2004)	
	Development for Biobased Technologies and Products through DOE's Energy Efficiency and Renewable Energy Programs (2004)	
	Renewables in Schools Projects (2006)	4
North Dakota	Biomass Energy Task Force (2007)	
	Biomass Incentive and Research Program (2007)	2

Table 2.7 Continued

State	Education and Consultation	Score
Ohio	Renewable Energy Supply Chain (2005)	
	Biomass Task Force (2003)	
	Biomass Project (2004)	
	Biomass Program (2005)	4
Oklahoma	Planning for an Oklahoma Forest Industry Technology Institute (2001)	1
Oregon	Oregon Biomass Working Group (2005)	
	Oregon Renewable Action Energy Plan (2005)	
	Oregon Strategy for Greenhouse Gas Reductions (2004)	3
Pennsylvania	Pennsylvania Biomass Working Group (2002)	1
Rhode Island	Biomass Heating Fuel Market Development for Southeastern New England (2004)	1
South Carolina	Renewable Resource Use and Development Program (2005)	
	South Carolina Biomass Market Development Program (2004)	2
South Dakota	Biofuels Economic Development Plan (2007)	
	Biomass Feasibility Study (2006)	2
Tennessee	Tennessee Bio-Based Fuels – Economics, Consumption, and Outreach (2005)	
	The Renewable Resource Development Program (2004)	
	Energy Efficiency Technologies and Waste Reduction in Tennessee's Forest Products Industry (2002)	
	Provision for Establishing an Alternative Fuel Research and Development Program (2006)	4
Texas	The Innovative Renewable Energy Demonstration Program (2006)	
	Harvesting Mesquite Biomass for Energy on Texas Rangelands (2003)	
	Alternative Fuel Program Support (2003)	3
Utah	Woody Biomass Utilization Study (2006)	1
Vermont	Agricultural Economic Development Plan for Biofuels (2005)	
	Biomass District Energy Program (2005)	2
Virginia		0
Washington		0
West Virginia	Biomass Working Group (2002)	
	Conceptual Review of West Virginia Biorefinery Options and Preliminary Economic Feasibility (2005)	
	Center for Biobased Materials (2006)	3

Table 2.7 Continued

State	Education and Consultation	Score
Wisconsin	K-12 Biomass Education (2004)	1
Wyoming		0

Table 2.8 The scores and policy ranking of the 50 states.

State	Tax Incentives		Subsidies and Grants		Financing		Rules and Regulations		Education and Consultation		Total	Ranking
	Score	Scaled	Score	Scaled	Score	Scaled	Score	Scaled	Score	Scaled		
Alabama	1	1	3	2.4	0	0.0	0	0	3	2.4	5.8	37
Alaska	2	2	3	2.4	2	1.5	0	0	0	0	5.9	36
Arizona	7	7	3	2.4	0	0.0	3	2.25	0	0	11.7	16
Arkansas	0	0	0	0	0	0.0	3	2.25	1	0.8	3.1	46
California	6	6	9	7.2	2	1.5	2	1.5	1	0.8	17.0	6
Colorado	4	4	3	2.4	0	0.0	2	1.5	3	2.4	10.3	23
Connecticut	3	3	7	5.6	1	0.7	5	3.75	2	1.6	14.7	9
Delaware	0	0	6	4.8	0	0.0	2	1.5	0	0	6.3	35
Florida	5	5	10	8	0	0.0	1	0.75	3	2.4	16.2	8
Georgia	8	8	0	0	0	0.0	0	0	1	0.8	8.8	28
Hawaii	6	6	1	0.8	3	2.2	4	3	1	0.8	12.8	11
Idaho	5	5	5	4	2	1.5	1	0.75	1	0.8	12.0	12
Illinois	2	2	5	4	3	2.2	3	2.25	0	0	10.4	21
Indiana	0	0	3	2.4	0	0.0	1	0.75	0	0	3.2	44
Iowa	9.5	9.5	1	0.8	11	8.0	3	2.25	1	0.8	21.4	1
Kansas	9	9	0	0	0	0.0	0	0	1	0.8	9.8	25
Kentucky	10	10	0	0	0	0.0	2	1.5	0	0	11.5	17
Louisiana	0	0	0	0	0	0.0	2	1.5	2	1.6	3.1	46
Maine	2	2	3	2.4	0	0.0	3	2.25	0	0	6.7	33
Maryland	3	3	0	0	0	0.0	2	1.5	0	0	4.5	40
Massachusetts	3	3	9	7.2	2	1.5	5	3.75	2	1.6	17.0	6
Michigan	5	5	3	2.4	0	0.0	2	1.5	1	0.8	9.7	26
Minnesota	2	2	6	4.8	1	0.7	5	3.75	0	0	11.3	18
Mississippi	0	0	0	0	3	2.2	1	0.75	0	0	2.9	49
Missouri	2	2	1	0.8	1	0.7	4	3	5	4	10.5	20

Table 2.8 Continued

State	Tax Incentives		Subsidies and Grants		Financing		Rules and Regulations		Education and Consultation		Total	Ranking
	Score	Scaled	Score	Scaled	Score	Scaled	Score	Scaled	Score	Scaled		
Montana	5	5	1	0.8	0	0.0	0	0	0	0	5.8	37
Nebraska	2	2	0	0	2	1.5	1	0.75	0	0	4.2	41
Nevada	0	0	0	0	0	0.0	4	3	1	0.8	3.8	42
New Hampshire	1	1	3	2.4	2	1.5	2	1.5	1	0.8	7.2	30
New Jersey	0	0	3	2.4	0	0.0	6	4.5	0	0	6.9	31
New Mexico	8	8	0	0	0	0.0	1	0.75	2	1.6	10.4	21
New York	2	2	1	0.8	0	0.0	7	5.25	1	0.8	8.9	27
North Carolina	6	6	7	5.6	5	3.6	3	2.25	4	3.2	20.7	2
North Dakota	5	5	1	0.8	0	0.0	6	4.5	2	1.6	11.9	13
Ohio	6	6	5	4	0	0.0	6	4.5	4	3.2	17.7	5
Oklahoma	0	0	0	0	2	1.5	2	1.5	1	0.8	3.8	42
Oregon	11	11	4	3.2	2	1.5	2	1.5	3	2.4	19.6	4
Pennsylvania	0	0	9	7.2	0	0.0	3	2.25	1	0.8	10.3	23
Rhode Island	1	1	3	2.4	0	0.0	3	2.25	1	0.8	6.5	34
South Carolina	4	4	5	4	3	2.2	0	0	2	1.6	11.8	15
South Dakota	3	3	1	0.8	0	0.0	2	1.5	2	1.6	6.9	31
Tennessee	0	0	0	0	2	1.5	0	0	4	3.2	4.7	39
Texas	5	5	0	0	0	0.0	6	4.5	3	2.4	11.9	13
Utah	5	5	0	0	0	0.0	2	1.5	1	0.8	7.3	29
Vermont	5	5	3	2.4	2	1.5	1	0.75	2	1.6	11.2	19
Virginia	0	0	0	0	0	0.0	4	3	0	0	3.0	48
Washington	14	14	3	2.4	3	2.2	2	1.5	0	0	20.1	3
West Virginia	0	0	0	0	0	0.0	1	0.75	3	2.4	3.2	44
Wisconsin	0	0	9	7.2	0	0.0	8	6	1	0.8	14.0	10
Wyoming	2	2	0	0	0	0.0	1	0.75	0	0	2.8	50

Table 2.9 Indices and ranking of state woody biomass policies based on different weighting methods.

State	# of regulations	ranking	Index same weight	Ranking	Index arb. weight	Ranking	Index var. weight	Ranking
Alabama	5	34	7.8	29	5.8	37	6.6	36
Alaska	3	46	5.0	42	5.9	36	5.9	37
Arizona	6	28	9.4	23	11.7	16	11.5	18
Arkansas	4	40	4.6	43	3.1	46	3.5	46
California	13	5	15.7	9	17.0	6	18.1	7
Colorado	10	14	11.5	18	10.3	23	10.9	22
Connecticut	13	5	16.2	8	14.7	9	16.4	10
Delaware	4	40	6.8	33	6.3	35	7.9	29
Florida	10	14	16.7	7	16.2	8	18.0	8
Georgia	4	40	6.2	37	8.8	28	7.6	31
Hawaii	9	17	12.0	14	12.8	11	12.2	14
Idaho	9	17	10.9	19	12.0	12	12.3	13
Illinois	7	22	10.3	22	10.4	21	11.2	19
Indiana	2	47	3.4	48	3.2	44	4.0	42
Iowa	12	9	18.8	3	21.4	1	19.0	3
Kansas	5	34	6.7	34	9.8	25	8.4	27
Kentucky	5	34	7.7	30	11.5	17	10.1	23
Louisiana	4	40	5.2	40	3.1	46	3.5	46
Maine	6	28	6.5	35	6.7	33	7.3	33
Maryland	5	34	3.7	45	4.5	40	4.2	41
Massachusetts	15	1	16.9	4	14.0	6	19.1	2
Michigan	7	22	6.0	24	4.7	26	9.9	24
Minnesota	9	17	10.5	16	9.3	18	12.8	11
Mississippi	2	47	3.2	49	2.9	49	2.6	49
Missouri	12	9	14.7	10	10.5	20	11.2	19
Montana	11	12	3.7	45	5.8	37	5.2	38
Nebraska	2	47	3.6	47	4.2	41	3.7	44
Nevada	7	22	5.6	39	3.8	42	4.4	40
New Hampshire	7	22	8.0	27	7.2	30	7.7	30
New Jersey	7	22	8.4	26	6.9	31	8.3	28
New Mexico	8	20	8.8	25	10.4	21	9.3	26
New York	10	14	10.5	21	8.9	27	9.6	25
North Carolina	15	1	22.1	1	20.7	2	21.4	1
North Dakota	12	9	12.9	13	11.9	13	12.2	14
Ohio	15	1	19.8	2	17.7	5	18.9	4
Oklahoma	5	34	5.1	41	3.8	42	3.8	43
Oregon	13	5	17.7	5	19.6	4	18.9	4

Table 2.10 Continued

State	# of regulations	ranking	Index same weight	Ranking	Index arb. weight	Ranking	Index var. weight	Ranking
Pennsylvania	7	22	11.8	15	10.3	23	12.8	11
Rhode Island	6	28	7.6	32	6.5	34	7.4	32
South Carolina	6	28	11.7	16	11.8	15	12.1	16
South Dakota	6	28	7.7	30	6.9	31	7.1	34
Tennessee	5	34	7.9	28	4.7	39	4.8	39
Texas	11	12	13.7	12	11.9	13	12.1	16
Utah	6	28	6.5	35	7.3	29	6.8	35
Vermont	8	20	10.9	19	11.2	19	11.1	21
Virginia	4	40	4.0	44	3.0	48	3.5	46
Washington	13	5	14.6	11	20.1	3	18.3	6
West Virginia	4	40	5.8	38	3.2	44	3.6	45
Wisconsin	14	4	16.8	6	14.0	10	17.1	9
Wyoming	2	47	2.1	50	2.8	50	2.5	50

Table 2.10 Correlation of the ranking of woody biomass policy index with those of other indices.

		Green Index	Tax climate index	GDP per capita	GHG emissions
Woody biomass policy index	Corr. coef.	0.4846**	-0.2231	0.0939	0.1249
	P-value	0.00036	0.11940	0.51636	0.38752
	N	50	50	50	50

NOTE: ** = Significant at 1% level.

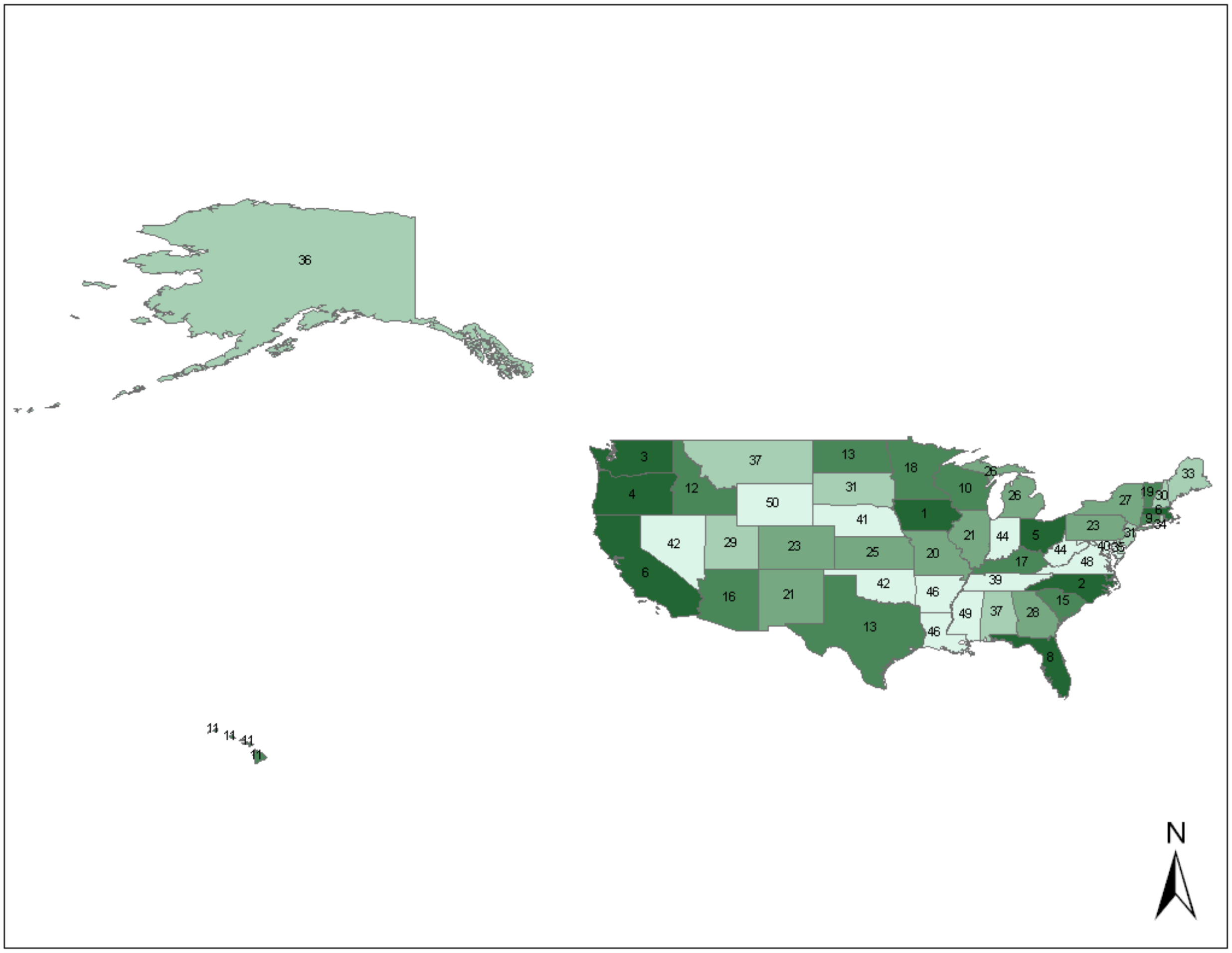

Figure 2.1 Geographical information of the state woody biomass policy index and ranking.

Chapter 3

Woody Biomass Policies and Location Decisions of the Bioenergy Industry in the Southern United States

Abstract

Woody biomass for bioenergy production has been included in relatively few renewable energy policies since the 1970s. Recently, however, several states have implemented a variety of new woody biomass policies to spur the establishment of new bioenergy industry. Establishing new woody biomass-based facilities in a specific state is affected by a number of factors such as the strength of these new policy incentives, resource availability, and the available labor force. This study employs a conditional logit model (CLM) to explore the effects of woody biomass policies on the siting decisions of new bioenergy projects relative to some of these other state attributes. The CLM results suggest that state government incentives are significantly related to state success in attracting new plants. The results have substantial implications regarding woody biomass policies and the creation of a new bioenergy industry.

Keywords: CLM, policy incentives, resource availability, state attributes

Introduction

Legislation has included woody biomass for renewable energy production since the 1970s. Recently, however, several states have implemented a variety of new woody biomass policies to spur the establishment of new bioenergy industry. Woody biomass policies can be categorized as tax incentives, subsidies and grants, financing and contracting, regulations, and education and consultation supports (Becker and Lee 2008). These statutes cover many aspects of project planning such as market demand, capital appropriation, and legal environment -- all of which are important for business investment.

The number and category of policies vary by state. This distinction suggests that the effects of policy incentives or the competitiveness for new projects differ by state, based on the assumption that a positive relationship exists between the strength of policy incentives and the number of new plants established. Yet, the significance of state woody biomass policies in new bioenergy plant location decisions largely remains unstudied.

In the past 20 years, several researchers have investigated how governmental policies influence firm location behavior, especially the impacts of environmental regulations on siting decisions (Jaffe et al. 1995; Levinson 1996; List and Co 2000). The results of the studies, however, are inconsistent. Some reveal no effect or a negative influence; others a positive relationship (Jeppesen and Folmer 2001). The explanations for these results also vary. More importantly, very few analyses have been focused on the forest products industry.

A few analysts have explored siting decisions of traditional wood products industry and the paper and allied products industry (Duffy 1994; Sun and Zhang 2001). Significant state factors identified include market conditions, unionization, resource endowment, and tax climate. The time-series cross-section model results of Sun and Zhang (2001) indicate that environmental stringency may have a negative impact on new plant locations in the long-run, while other studies reveal no effects on the location choice of forest product firms.

Young et al. (2011) utilized logistic regression to identify local factors that affect the siting decision of wood using bioenergy plants. Due to the bioenergy plant data limitation, traditional wood-processing facilities were included to increase the number of observations. Significant factors identified include biomass availability, population, railroad availability, the number of wood processing mills, and logging residue collection costs.

The current study examines the impacts of governmental policies, including woody biomass incentives and environmental regulations, on the siting decisions of bioenergy plants. Other state attributes related to new bioenergy firms siting decisions are also identified. Since the southern states represent one-third of the forest inventory and account for nearly one-half of the timber removals in the United States, forest biomass utilization for bioenergy will be more feasible and imperative in the South. Therefore, this study investigated the effects in the 13 southern states[1], but the results may be meaningful nationally.

Methods and Data

The conditional logit model (CLM) was used in this study to investigate the location choices of the new bioenergy industry using woody biomass in the southern United States. Establishment data, the number of new plants built after the implementation of woody biomass policies, were employed as the measure of investment activities for the CLM.

CLM for the number of new plants

Developed by McFadden (1974), the CLM is one of the econometric models widely used for plant location decision analysis (Carlton 1983; List and Co 2000; Sun and Zhang 2001). Following previous work (Bartik 1988; Levison 1996; Sun and Zhang 2001), this study assumes that each firm screens locations based on a latent profit function that is dependent on a variety of state attributes where it plans to locate. Firms will locate in a state if its expected profits exceed those of all other states. The profit function can be written as:

$$\pi_{ij} = \beta' X_j + \mu_{ij} \qquad (1)$$

---

[1] Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

where π_{ij} is the expected profits of firm *i* if locating the new plant in state *j*, X_j is a vector of observable characteristics of state *j*, β is a vector of estimated coefficients, and μ_{ij} is the random disturbance term. Assuming that the disturbance terms are independently and identically distributed (iid) and following a type I extreme value distribution, the probability of a new bioenergy plant *i* locating in state *j* is:

$$p_{ij} = \frac{e^{\beta' x_{ij}}}{\sum_{k=1}^{K} e^{\beta' x_{ik}}} \qquad (2)$$

where *k* indexes the state, *K* is the total number of southern states, and the parameter vector β is estimated using the maximum likelihood method with the log-likelihood function given by:

$$\ln L(\beta) = \sum_{i=1}^{N} \sum_{j=1}^{K} \ln p_{ij} \qquad (3)$$

The assumption that the disturbance terms μ_{ij} in equation (1) are iid is quite strong. This assumption imposes the “Independence of Irrelevant Alternatives” (IIA) restriction on the predicted probabilities, i.e., the probability ratio of a firm i locating in state j to state k (Pj/Pk) is independent of the remaining probabilities (Greene 1993). Rather than using regional dummy variables to correct this problem, which is more appropriate for the analysis of whole nations (Levinson 1996; List and Co 2000), this study applied the IIA test proposed by Hausman and McFadden (1984). In case of failure of this assumption, a sequential logit model can be employed.

Variables and Data

The dependent variable was a dummy indicating whether a new bioenergy plant selected to locate in an individual southern state. Electricity generating plants, pellet plants, and biorefinery facilities that have been established or announced in the past two decades were included in the analysis. The data were obtained from Forisk Consulting LLC (Forisk Consulting LLC 2010). A few additional projects were identified through online searching. The number of new plants sited after state regulations and programs were adopted is critical for this analysis. Based on the data, most of bioenergy plants were built or announced after 2000, indicating that these data were consistent with the fact that most woody biomass policies were implemented after 2000.

The independent variables consisted of two categories: policy attributes and other observable state characteristics. The policy attributes considered in this study include governmental incentives (*POLI*) through various woody biomass policies, the stringency of environmental regulations (*ENVI*), and business taxes (*TAX*). Since the federal policies and programs provide the same incentives across the southern states, they will not affect the location decision of new firms and, therefore, were excluded from this analysis. To quantify the strength of state government incentives, the state woody biomass policy index (Table 3.1) developed by Guo (2011) was used. It scored each statute and weighted different categories of incentives based on their importance to new plant investors.

Prior research suggests that bioenergy production entails water evaporation loss or requires large amounts of water, as well as result in a potentially large pollution load on aquatic systems (Frings et al. 1992; Giampietro et al. 1997; Berndes 2002). Water and waste pollution originating from some bioenergy plants have also been reported. Thus, environmental regulations may influence the locations of new bioenergy facilities. Therefore, we included environmental stringency as an explanatory variable. The industry-adjusted index of state environmental compliance costs created by Levinson (2001) was used as an indicator of environmental regulatory stringency. This index was chosen because it controls for state industrial compositions at the two-digit SIC code level, eliminating the bias that high compliance costs are associated with the number of polluting industries rather than a state's regulations.

Evidence from previous research suggests that business taxes can affect investment activities substantially (Sun and Zhang 2001; Guimaraes et al 2004). To account for this effect, the state business tax climate index (SBTCI) was used as an explanatory variable for the analysis. It consists of five components: the corporate tax index, property tax index, sales tax index, unemployment tax index and individual income tax index. The SBTCI fully represents the competitiveness of state tax systems. Higher scores indicate a more favorable tax system for new business and therefore this variable is expected to have a positive sign for the coefficient.

Other state attributes that may affect new plant location decisions are those typically used in previous work such as resource endowment, traditional woody processing industry, and labor force (Table 3.2). Resources involve biomass availability and price. Biomass resources are especially important for new bioenergy plants. Facilities are generally located close to resources to minimize transportation costs. To examine its significance and control for the fact that larger states may have more resources and be more likely to be selected, the variable of logging residue availability (*LOG_RESI*) was created by dividing the total amount of logging residues in each state by its land area. It represents the abundance of woody biomass resources within a certain distance. The total amount of logging residues was obtained from BioSAT (2011). Land area data were obtained from the Infoplease (2011).

The delivered price of pine or hardwood pulpwood (*PULP*) was used to indicate competition from existing timber industry and woody biomass costs. The choice of delivered prices depends on the majority of species in an individual state. For example, hardwood is the dominant forest type in Tennessee. It will also be more likely used for bioenergy production. Therefore, hardwood rather than pine pulpwood price will be more closely represent timber market conditions in Tennessee.

The number of primary wood-processing mills was considered to reflect the agglomeration effects of wood processing industry. In order to account for differences in manufacturing activity by state, a variable *PRI_MILL* was created by dividing the number of primary wood-processing mills by the number of manufacturing mills in each state. This variable also served as an indicator of the major sources of woody biomass used for bioenergy. If it has a significant positive effect, the bulk of feedstocks for bioenergy plants probably will be mill residues. If it has a negative sign, thinnings and logging residues are likely to be the main feedstocks. The number of paper and pulp mills was also used as a measure of the extent of competition for small diameter wood resources. Similarly, a variable *PP_MILL* was created by dividing the number of paper and pulp mills by the number of manufacturing mills. *PP_MILL* was expected to have a negative sign if competition for small wood materials exists. These two variables may also seize some of unobserved state characteristics that influence the birth of a new industry. The number of wood processing mills was obtained from the BioSAT (2011). The manufacturing mill data were obtained from Manta (2011).

To capture the effects of labor force, average hourly wage rate (*WAGE*) was used as control variables in the model. The summary of independent variable statistics and data sources are presented in Table 3.2.

Empirical Results

The Hausman test result failed to reject the null hypothesis of IIA at a 95% significance level, suggesting that there is no need to specify a model that is free from IIA. Based on the likelihood ratio test, the CLM regressions were significant at the 0.1% level, indicating that the model fits the data well. The results revealed that five factors are significantly related to the siting decision of new bioenergy plants (Table 3.3). Three coefficients were significant at the 1% level and the other two at the 5% and 10% level, respectively. The woody biomass policy was significantly and positively related to the siting decision of new bioenergy industry at 5% level. The logging residue availability and the state business tax climate index were significantly and positively related to bioenergy plant location choices. Controlling for differences in manufacturing activity by state, the number of primary wood-processing mills was negatively related and the number of pulp and paper mills had a positive sign. However, neither was significantly correlated with locating new bioenergy plants. The delivered pulpwood price and the average wage rate were positively correlated with the siting choice of new bioenergy projects. The coefficients of environmental regulation stringency had negative signs but were not statistically significant.

Discussion

This study assessed the effects of state attributes, especially the state woody biomass policy incentives, on the siting decisions of new bioenergy plants. Previous research has demonstrated that establishment-level data rather than aggregate data (e.g. net investment or employment growth in bioenergy industry) are more appropriate for investigating the location choices of new plants (Levinson 1996). Hence, the number of new bioenergy plants was employed as the measure of investment activities for the CLM.

A state woody biomass policy index created by Guo (2011) was used to indicate the strength of government support for the forest biomass utilization. Results suggested that this attribute significantly impacted the location choices of new bioenergy plants using woody biomass. Levinson's (2001) industry-adjusted index of state environmental compliance costs was employed to represent the environmental regulatory stringency of each state. It was insignificantly related to siting decisions, which is consistent with previous research (Levinson 1996; Sun and Zhang 2001).

Tax was identified as a significant attribute influencing plant location choices. Rather than per capita property tax, the state business tax climate index (SBTCI) was employed for the analysis. It consists of five components and fully represents the competitiveness of each state's tax system. This state attribute had highly significant positive effects on the siting decision of new bioenergy plants.

Logging residue availability within a certain distance was significantly and positively related to the location choices. This result is consistent with findings of previous studies that that forest resources positively affect location decisions of forest products industry (Sun and Zhang 2001; Young et al. 2011). Duffy (1994) concluded that commercial forest holdings had no effect on the growth of the lumber and paper industry. However, logging residues or forest inventory rather than commercial forest holdings is a more appropriate measure of resource availability for this study. Forest biomass used by bioenergy plants is mostly small diameter wood or solid wood waste and not large commercial timber. Total logging residues reflect the general availability of woody biomass resource such as logging residues and forest thinnings.

Another explanation for the contradictory results could be the difference in transportation costs of large and small wood materials. Due to the bulky nature and high moisture content of small diameter wood, the procurement costs are substantially larger than that for traditional forest products (Sun and Zhang 2001; Guo et al 2007). Therefore, the bioenergy industry should be located even closer to forests than other wood product industries to minimize raw material costs. Thus, the location of new bioenergy plants should be more resource-oriented than other wood industries, and it is reasonable that total logging residue availability affects siting decisions significantly.

The number of primary wood-processing mills and pulp and paper mills were not significantly correlated with the location decision of new bioenergy plants, after accounting for differences in manufacturing activity by states. This suggests that there was no agglomeration effect of bioenergy plants and traditional wood processing industry. It further indicates that thinnings and logging residues rather than mill residues or pulpwood will be the major sources of bioenergy feedstocks.

Pulpwood price (*PULP_PRI*) was positively correlated with location decisions, suggesting that bioenergy plants are more likely to locate in a state where more pulp and paper mills exist. This was not revealed by the variable *PP_MILL* that controlled for overall manufacturing activitiy differences.

The hourly mean wage rate (*WAGE*) was positively correlated with siting. This measure of labor force represented the general state hourly pay of all industries. It indicates that bioenergy plants are locating where there is an available skilled work force. The other explanation could be that a large number of industries in a state resulting in a higher wage rate generated a higher demand for energy.

Conclusion

This study explores the effects of state attributes on siting decisions of bioenergy plants in the southern US. The results indicate that many state characteristics influence location choices of the bioenergy industry such as woody biomass policies, forest resource endowment, tax system, and labor force. This industry may be more resource–oriented than other forest product industries due to the nature of the small diameter wood used. This has important implications for state woody biomass policies. Currently, some regulations and programs have addressed the procurement costs of forest biomass. These government incentives and support significantly affect the state screening of new plants. The significance of the tax system on location choice also proves this point. A better business tax climate attracts more bioenergy plants. States such as North Carolina, Florida, Texas, and South Carolina provide strong tax incentives on woody biomass utilization (Guo 2011). These polices will be favorable for investments in new bioenergy plants.

This study first used the CLM to explore the effects of woody biomass policies and other state attributes on the location decisions of bioenergy plants. The bioenergy plant data from Wood Bioenergy US, Forisk Consulting (2011) is critical for this analysis. Results indicate that there were no agglomeration effects of new bioenergy industry with traditional wood processing industry. This implied the possible problem of predicting desirable location for bioenergy facilities using the data of traditional wood-processing plants. Though forest resources were significant factors for both, other attributes considered for bioenergy project location screening could be different.

Due to the very large options included for the CLM if using county level data, this research used state level data to examine the significance of state woody biomass policies and other characteristics on the birth of bioenergy industry. Some county or even local level attributes are likely to affect location choices (Young et al. 2011). Future studies using different methods might identify some local level explanatory factors.

APPENDIX: TABLES

Table 3.1 Woody biomass policy scores and ranking of the southern states.

State	Score	Ranking
Alabama	5.8	7
Arkansas	3.1	10
Florida	16.2	2
Georgia	8.8	6
Kentucky	11.5	5
Louisiana	3.1	10
Mississippi	2.9	13
North Carolina	20.7	1
Oklahoma	3.8	9
South Carolina	11.8	4
Tennessee	4.7	8
Texas	11.9	3
Virginia	3.0	12

Table 3.2 Independent variable definition and data sources

Variable	Definition	Mean	Std. Dev.	Source
POLI	Woody biomass policy index	8.253846	5.566661	Guo (2011)
ENVI	Index of state environmental compliance costs	1.102308	0.261371	Levinson (2001)
TAX_CL	Business tax climate index	5.383826	0.554108	Padgitt (2010)
LOG_RESI	Logging residue availability divided by land area (thousand dry tons/square mile)	65.17325	33.32587	BioSAT (2011) Infoplease (2011)
PULP_PRI	Pulpwood delivered price ($/ton)	0.468191	0.372775	Timber-Mart South (2009) Nevins (2009)
PRI_MILL	Number of primary wood processing mills divided by number of manufacturing mills	0.036007	0.038926	BioSAT (2011) Manta (2011)
PP_MILL	Number of pulpwood and paper mills divided by number of manufacturing mills	27.19127	2.614448	BioSAT (2011) Manta (2011)
WAGE	Hourly mean wage rate	17.87846	1.407318	USDL (2009)

Table 3.3. Empirical results of the conditional logit model.

Variable	Coefficient	t-ratio
POLI	0.087818**	2.02
ENVI	-0.18439	-0.26
TAX_CL	1.140952***	2.64
LOG_RESI	0.031817***	3.22
PULP_PRI	0.254792*	1.75
PRI_MILL	-0.14186	-0.21
PP_MILL	2.94012	1.14
WAGE	0.441937***	3.72
Log likelihood	-343.44044	
Chi-squared	77.47	
No. of observations	1937	

NOTE: *** = Significant at 1% level,** = Significant at 5% level,
* = Significant at 10% level.

Chapter 4

Forest Biomass Supply for Bioenergy Production and its Impacts on Roundwood Markets in Tennessee

This chapter is revised based on the following paper:

Guo, Z., D.G. Hodges, and R.C. Abt. 2011. Forest Biomass Supply for Bioenergy Production and its Impacts on Roundwood Markets in Tennessee. *Southern Journal of Applied Forestry* 35(2):80-86.

My primary contributions to this paper include (i) reviewing literature, (ii) running the SRTS model for prediction of roundwood markets, (iii) analyzing results, and (iv) writing the paper.

Abstract

The utilization of forest biomass as an alternative source for bioenergy production has become a significant issue in Tennessee. This study used the Sub-Regional Timber Supply (SRTS) model to analyze the regional aggregate forest biomass feedstock potential and the impacts of additional pulpwood demand on the regional roundwood market through 2030. Two scenarios examined the impacts of building a biorefinery facility of 20 and 50 million gallons annual capacity in the state in 2015. The third scenario investigated the impacts of an annual demand increase for pulpwood that is similar to the Energy Information Administration (EIA) reference case. The projection results reveal that there is sufficient hardwood pulpwood supply for a 50M biorefinery facility in Tennessee. It is possible to meet the annual demand increase for pulpwood without affecting the hardwood pulpwood market in the short run, but not in the distant future. The additional demand for softwood pulpwood will affect the softwood market substantially, but the impacts on the hardwood market are comparatively small. Hence, it is more feasible to increase the use of hardwood pulpwood for renewable energy rather than softwood pulpwood. These results will be very helpful in sustainably supplying forest biomass for bioenergy production in Tennessee.

Keyword: forest inventory, projection, removals, roundwood prices, SRTS model

Introduction

Energy consumption in Tennessee totaled 2,313.2 trillion Btu in 2006. Biomass supplied around 51.9 trillion Btu, or 2.2% of the state total, ranking 20th nationally (EIA 2009a). In addition to the interest in agricultural biomass such as switchgrass (*Panicum virgatum* L.), willow (*Salix* spp.), and agricultural residues, interest in the utilization of forest biomass as an alternative source for bioenergy production is increasing in Tennessee. With the announced construction of a pilot biorefinery facility partly using wood as a feedstock, forest biomass will be increasingly important for bioenergy.

Approximately 1.5 million green tons of forest harvest residues are produced in the state annually. The Energy Information Administration (EIA) reference case projected that energy generation from wood and other biomass will increase by 5.2% annually between 2007 and 2030 nationally (EIA 2009b). Assuming this 5.2% annual growth, forest biomass demand will increase from approximately 1.5 million to more than 5 million green tons in Tennessee by 2030. How will this additional demand for forest biomass influence roundwood markets and the sustainability of forest management and the roundwood supply?

Unlike most southern states, Tennessee's timberlands are dominated by hardwoods. Due to the substantial impact of the southern pine beetle (SPB) (*Dendroctonus frontalis*

Zimmerman) outbreak and other disturbances such as weather, animals, and humans, the net growth of softwood was negative from 1999 to 2004 (Oswalt et al. 2009). Based on the recent annual Forest Inventory and Analysis (FIA) panel data, softwood removals declined at an approximate annual rate of 20% from 2005 to 2007, possibly because of the current economic downturn and the resulting closure of some wood processing facilities. The magnitude of decline in hardwood removals was comparatively small during the same period, around 5%. In the situation of growing demand for biomass, it is imperative to investigate how an increased use of forest biomass will affect roundwood markets and the sustainability of roundwood and forest biomass supply.

Previous research has examined the interactions between traditional timber use and biomass supply. Industrial roundwood is considered one of the key factors determining forest biomass availability for bioenergy (Smeets and Faaij 2007). The price interactions between fuelwood and traditional wood products have been investigated, and competition between biomass supply and conventional wood uses has been recognized (Sedjo 1997; Ince 2007). Some studies suggest that it is unlikely that roundwood will be utilized for bioenergy because sawtimber is too expensive and competition for pulpwood will drive prices up (Hazel 2006; La Capra Associates 2006). However, this will depend on regional market conditions.

Given the growing demand for forest biomass for bioenergy, this study analyzed its potential impacts on roundwood markets as well as the sustainability of biomass supply and forest inventory in Tennessee. The specific objectives of this study were to: (1) examine the aggregate forest biomass feedstock potential; (2) investigate the impact of forest biomass supply on the roundwood market; and (3) explore the possibility of sustainably supplying forest biomass for bioenergy in Tennessee.

Methods

This study predicted the roundwood markets, inventory, and forest removals of three scenarios in Tennessee from 2005 through 2030. The sub-regional timber supply model (SRTS) default demand for each wood product, which was based on the 2005 USDA Forest Service Inventory and Analysis data, was used as the starting point for all projections. In order to reflect the decrease in forest removals from 2005 to 2007 due to mill closures, the projections of demand for softwood and hardwood products were reduced by 20% and 5% annually through 2007. To explore the effects of increased demand on roundwood market, a constant demand for forest biomass from 2007 to 2030 was assumed for the projection of the base scenario for comparison with other scenarios. Three alternative scenarios of additional forest biomass supply for bioenergy production were then examined and compared. Logging residues were estimated using a recovery factor of 40% (Walsh et al. 2000; Galik et al. 2009). Forest biomass supply for bioenergy production, including pulpwood and logging residues, was predicted for each scenario.

The first alternative scenario increased demand by assuming that a biorefinery facility with an annual capacity of 20 million gallons would be constructed in Tennessee in 2015. The consequences of a facility with a larger annual capacity (50 million gallons) were then investigated in the second alternative scenario. Since biorefinery facilities need clean chips as feedstock, it was assumed that 200 or 500 thousand dry tons of pulpwood would be used as feedstock annually under these two scenarios respectively, based on the conversion factor of 100 gallons per dry ton (Timber Mart-South 2008). Assuming a 50% wood moisture content, 400 thousand or one million green tons of pulpwood would be consumed annually beginning in

2015 for the two scenarios. Because hardwood acreage and annual removals are much larger than softwood in Tennessee, this study assumed that the annual biomass consumption of the facility would consist of 15% softwood and 85% hardwood for these two alternative scenarios.

Based on the demand of 2030 predicated by the EIA reference case, the third alternative scenario examined the impact of 155,300 green tons of annual pulpwood demand increase from 2009 to 2030. It projected the market, inventory, and removal response if the additional annual demand consisted of 5% softwood pulpwood (7,765 green tons) and 95% hardwood pulpwood (147,535 green tons). This different composition was used to reduce the dramatic effects of the very large demand on softwood markets considering the small softwood acreage in Tennessee.

The Sub-Regional Timber Supply (SRTS) model was used for the analysis (Abt et al. 2009). The 'demand driven' mode was used, which assumes that harvest and stumpage price respond to a change in demand. The demand price elasticities were 0.1 for pulpwood and 0.4 for all other roundwood products (Polyakov et al. 2009). The effect of increasing demand for pulpwood will depend on supply. The supply price elasticity was assumed to be 0.5 for all wood products, which indicated that a 1% change in stumpage price would increase harvest by 0.5%. The supply inventory elasticities were set to 1.0 for softwood products and 0.6 for hardwood products, assuming 40% of the hardwood inventory may be unavailable for wood utilization. Based on these assumptions, an increase in demand will raise both the price and the harvest, but the harvest will not increase proportionately, since the price increase dampens some of the harvest (Abt et al. 2009). In other words, the pulpwood alone will be too expensive to meet the demand. Therefore, other sources of biomass such as logging residues will be required. The amount of other biomass needed was also predicted for all three alternative scenarios.

Simulation Results

Roundwood Markets with Constant Demand

The roundwood markets, inventory, and forest removals with no demand increase for forest biomass was projected as a base case for comparison (Figure 4.1). It indicated that the softwood pulpwood removals will remain around 65% of the 2005 removals through 2030. The softwood pulpwood inventory will be stable through 2015 and then increase to more than 130% of the 2005 inventory. The softwood pulpwood price will fluctuate substantially during this period. It will remain around 65% of the 2005 price through 2015, then decrease by more than 20% due to the increase in inventory, and finally rise to 60% of the 2005 price. Softwood sawtimber inventory and removals generally follow the same trends as softwood pulpwood. The inventory will gradually increase to 120% of the 2005 levels from 2016 to 2030. The fluctuation in softwood sawtimber price will be greater than that of pulpwood. The price index will increase to 113 in 2015 and then decline to 84 in 2023 before regaining most of this by 2030.

The hardwood pulpwood and sawtimber markets will follow the same trend. The inventories will continue to increase and the indices will exceed 140 by the end of the projection (Figure 4.1). The removals will increase slightly. Since inventory increases much faster than harvest, the prices for both pulpwood and sawtimber will continue to decline; in 2030, they will be 40% and 30% lower than 2005 prices, respectively.

Roundwood Markets with the Construction of a 20M Biorefinery Facility

The market impacts of building a biorefinery facility with an annual capacity of 20 million gallons in 2015 are shown in Figure 4.2. An annual additional demand for 60 thousand green tons of softwood pulpwood beginning in 2015 will increase the harvest slightly. By 2030, the removals will grow to around 80% of the 2005 harvest level. The inventory will not change noticeably with the additional pulpwood demand. The softwood pulpwood price will exhibit a small increase in 2015. Prices after 2015 will be more than those with no additional demand, but will remain below the 2005 price through 2030. The impacts on the softwood sawtimber market will be minor.

In general, the hardwood market will remain unchanged, except for the small increases in removals and the price of hardwood pulpwood in 2015 due to the additional demand for 340 thousand green tons of hardwood pulpwood (Figure 4.2). The removals of hardwood pulpwood will increase to the same level as the 2005 removals and remain stable through 2030. The price of hardwood pulpwood will be slightly higher than that with no pulpwood demand increase for a biorefinery facility by the end of the projection.

Increased pulpwood removals due to the additional demand from 2015 are presented in Figure 4.3. Annual hardwood pulpwood availability for biofuel production will be approximately 285 thousand green tons through 2030. Softwood pulpwood availability will increase slightly, from around 50 to 70 thousand green tons from 2015 to 2030. Total annual pulpwood supply for the biorefinery facility is estimated at approximately 345 thousand green tons. This suggests a shortfall of 55 thousand green tons in annual pulpwood supply for a 20M biorefinery facility. Harvesting residues will increase to more than 1.5 million green tons in

2015 and keep increasing through 2030. By the end of the projection, biomass availability for bioenergy projection in Tennessee will exceed 1.9 million green tons.

Roundwood Markets with the Construction of a 50M Biorefinery Facility

Building a biorefinery facility with an annual capacity of 50 million gallons in 2015 will produce much more significant effects, particularly in the softwood market (Figure 4.4). The additional annual demand for 150 thousand green tons of softwood pulpwood will increase the harvest to more than 80% of the 2005 removals; as a result, the softwood pulpwood price will increase to the 2005 price in 2015. It will then fall through 2021 due to the increase in inventory. By the end of the projection it will increase to over 120% of the 2005 price, because of the increased harvests and relatively slow growth of inventory. The projection of softwood sawtimber will follow the same trend as the base case, except for the slightly lower inventory and higher price by the end of projection relative to the no demand increase case.

Due to the additional annual demand for 850 thousand green tons of hardwood pulpwood from 2015, hardwood pulpwood removals will increase to more than the 2005 removals through 2030 (Figure 4.4). As a result, the hardwood pulpwood price will increase to 96% of the 2005 price in 2015, but decline thereafter because of the continuously increasing hardwood pulpwood inventory. By the end of the projection, the inventory of hardwood pulpwood will be slightly lower and the removals and price will be slightly higher than those with a biorefinery facility of 20 million gallons. The impacts on the hardwood sawtimber market will be insignificant.

Hardwood pulpwood availability for biofuel production will slightly decrease from 666 to 639 thousand green tons from 2015 to 2030 (Figure 4.5). Annual softwood pulpwood supply will range from 108 to 118 thousand green tons. Thus, the annual pulpwood supply for the biorefinery will approximate 765 thousand green tons. An additional 235 thousand green tons of biomass will still be needed to meet the demand of a 50M biorefinery facility. Harvest residues will increase to approximately 1.6 million green tons in 2015 and continue to increase slowly through 2030. By the end of the projection, biomass availability for bioenergy projection in Tennessee will reach about 2.4 million green tons.

Roundwood Markets with Demand Increase Similar to the EIA Reference Case

The projection indicated that increasing both softwood and hardwood pulpwood demand similar to the EIA reference case will affect roundwood markets significantly (Figure 4.6). An annual increase in softwood pulpwood demand of 7,765 green tons will result in a continuous increase in harvest. By 2030, it will increase to approximate the 2005 removals. Inventory will increase with a growth rate less than that of the base case. Consequently, the price of softwood pulpwood will increase to around 150% of the 2005 price. The projection of the softwood sawtimber market will generally follow the same trend as with no biomass demand increase. But the inventory will be slightly less than the base case, which will result in an increase in softwood sawtimber price to 140% of the 2005 price by 2030.

The removals of hardwood pulpwood will continuously increase from 2009 and exceed 140% of the 2005 removals, as a result of the 147,535 green tons of annual hardwood demand increase. The inventory will continue growing, but the speed of inventory growth will be less than that of the base case. Since the removals increase at a faster rate than inventory, the price of hardwood pulpwood will continue to rise. By 2030, it will equal 160% of the 2005 price, but the impacts on hardwood sawtimber market will be minimal.

Biomass availability of the third scenario is shown in Figure 4.7. Hardwood and softwood pulpwood supply will increase to 2.5 million and 163 thousand green tons, respectively, by 2030. Harvesting residues will increase to over 1.9 million green tons. By the end of the projection, biomass availability for bioenergy projection in Tennessee will be over 4.6 million green tons. However, there will be a shortfall as large as 708 thousand green tons of pulpwood to meet the demand by 2030.

Discussion

The projection of roundwood markets indicated that the softwood prices are sensitive to market changes in Tennessee. The softwood inventory will grow at a faster rate from 2015 to 2021 than in the period from 2005 to 2015, resulting in fluctuations in softwood prices even with no additional demand for softwood. The additional annual demand of 60 thousand green tons of softwood pulpwood for a 20M biorefinery facility will provide a positive incentive to the softwood market. It will raise the softwood pulpwood price but not above the 2005 price during the projection period. An annual demand for 150 thousand green tons of pulpwood (50M facility) will cause greater fluctuations in softwood prices. But the softwood (including pulpwood and sawtimber) prices will not exceed 120% of the 2005 prices until 2029. The sensitivity of the softwood market can be attributed mainly to the great impact of the SPB outbreak, the relatively small softwood acreage in Tennessee, and the effect of mill closures.

First, the most destructive outbreak of SPB since the 1970s affected the softwood inventory substantially. From 1999-2002, it affected approximately 350 thousand acres, killing an average of 8.5 and 6.3 million trees per year in the East and Plateau regions, respectively. As a result, annual softwood net growth between 1999 and 2004 decreased sharply to 38 million cubic feet (slightly over a thousand green tons), only a quarter of net growth between

1989 and 1998 (Cassidy 2005, Oswalt et al. 2009). Other factors such as weather, animal, and human disturbances also influenced Tennessee forests, but they affected both softwood and hardwood inventories and their impacts were much smaller than SPB. These disturbances led to the negative net growth of softwood inventory and, consequently, the sensitive softwood market.

Second, softwood stands account for less than 7% of Tennessee's timberlands (Oswalt et al. 2009). Including oak-pine mixed stands (8% of Tennessee's timberlands), the total softwood area is estimated to be around 2 million acres. Such a small acreage of softwood stands can be easily affected by various disturbances. The loss of an estimated 225 thousand acres of loblolly-shortleaf pine between 1999 and 2004 made the softwood markets more sensitive to demand changes.

Third, the closure of wood processing mills greatly reduced the demand for softwood. The softwood removals declined by 20% annually between 2005 and 2007. This severely decreased softwood pulpwood and sawtimber prices to less than 60% and 80% of the 2005 prices, respectively. In this situation, small increases in the softwood demand or inventory could result in the fluctuations of stumpage prices.

The hardwood market is relatively insensitive to the projected additional demand. The projections indicate that the hardwood inventory will grow constantly and significantly through 2030. Hardwood prices will continue to decline through 2030 with no additional demand for roundwood. Additional annual demand for 850 thousand green tons of hardwood pulpwood will increase removals to slightly more than the 2005 removals. However, hardwood pulpwood price will still decline after a small spike in 2015. Therefore, the additional demand for hardwood pulpwood for a biorefinery facility of 50 million gallons will not influence pulpwood inventory and prices substantially. Its impacts on the hardwood sawtimber market in Tennessee are even less. Since there will be sufficient supply of hardwood pulpwood for the new facility and traditional wood processing industries with much lower prices, increased use of sawtimber is not projected to occur. Thus, the sawtimber market will be generally the same as the base case.

The annual pulpwood demand increase by 155,300 green tons (similar to the EIA reference case) will greatly influence roundwood markets. Both softwood and hardwood pulpwood prices will exceed 150% of the 2005 prices by 2030. Even the softwood sawtimber price will increase to 140% of the 2005 level. This scenario is equivalent to three 50M biorefinery facilities being built by 2030. Though this high demand increase will probably not occur, these results provide us a useful reference of how large pulpwood demand increases affect roundwood markets.

This study projected the responses of the inventory, removals, and prices to additional demand for pulpwood for bioenergy production in Tennessee. The supply of pulpwood and logging residues under the three alternative scenarios will not meet the demand for forest biomass, since the price increase dampens some of the harvest (Abt et al. 2009). In addition, the higher the additional demand, the larger the shortfall of pulpwood will be. Therefore, other sources of forest biomass such as wood-processing industry residues and urban wood waste will need to be considered for biofuel production.

Predicting roundwood markets can be greatly influenced by the price elasticity values in SRTS. Larger demand price elasticities such as 0.5 will lead to much higher softwood product prices, especially when facing high pulpwood demand. This study, due largely to historic trends in the state (Oswalt et al. 2009), assumed constant forest land acreage in

Tennessee during the projection period. However, if there is a significant increase in pine plantation or hardwood forest areas due to policy incentives or other reasons, the inventories will grow at a faster rate. Consequently, the impacts of large forest biomass demand on the wood product prices will become smaller. The sensitivity of roundwood markets to additional pulpwood demand will decrease. Forest biomass availability will also increase. Yet, the slight decrease in forest acreage between 1999 and 2004 could also be a precursor of decline in land area because of fragmentation, parcelization, or other land-use changes (Oswalt et al. 2009). If this trend continues, any additional demand for forest biomass will have greater impacts on the roundwood markets. Forest biomass availability for biofuel production will decrease.

Conclusion

Tennessee's softwood market is more sensitive to increases in demand due to bioenergy production than its hardwood market. However, an increased demand for a 50 million gallon biorefinery (15% of which will be softwood) will not lead to higher prices or cause inventory fall, at least during the projection period. The hardwood market is relatively stable. With the annual additional demand of a 50 million gallon capacity biorefinery in 2015 (85% hardwood), hardwood inventory will continue to grow at a faster rate than removals and the price will decline. Therefore, there is potential to supply more hardwood pulpwood as feedstock for a biorefinery facility.

The demand similar to the EIA reference case would affect roundwood markets substantially. Softwood and hardwood pulpwood removals will increase at a faster rate than inventory growth, which will result in rising pulpwood prices. The hardwood pulpwood price will exceed the 2005 price by 2015 and will keep increasing to 160% of the 2005 price by 2030. Though the softwood pulpwood price will not reach the 2005 price till 2026 with a small annual increase (less than 8 thousand green tons) in demand, it will rise quickly to 150% of the 2005 price by 2030. Also, the large annual demand increase will cause the softwood sawtimber price to increase to 140% of the 2005 price by the end of the projection. Therefore, it is possible to meet the annual growth of forest biomass demand without affecting the roundwood markets in the short run but not in the long run. Also, increasing pulpwood removals and the resulting price increases may draw the attention of environmental and social advocacy organizations and increase the scrutiny of timber harvesting and forest functions.

This study reveals that additional demand for pulpwood for new biorefinery facilities may stimulate pulpwood markets in Tennessee. However, the increase in demand similar to the EIA reference case cannot be met without increasing the total forest area or the management intensity of existing forests. Based on the current roundwood markets, it is more feasible to increase the use of hardwood pulpwood for renewable energy rather than softwood pulpwood. These results will be very helpful in sustainably supplying forest biomass for bioenergy production. Future study should consider the impacts of land use change as well as markets in neighboring states on biomass supply in Tennessee.

APPENDIX: FIGURES

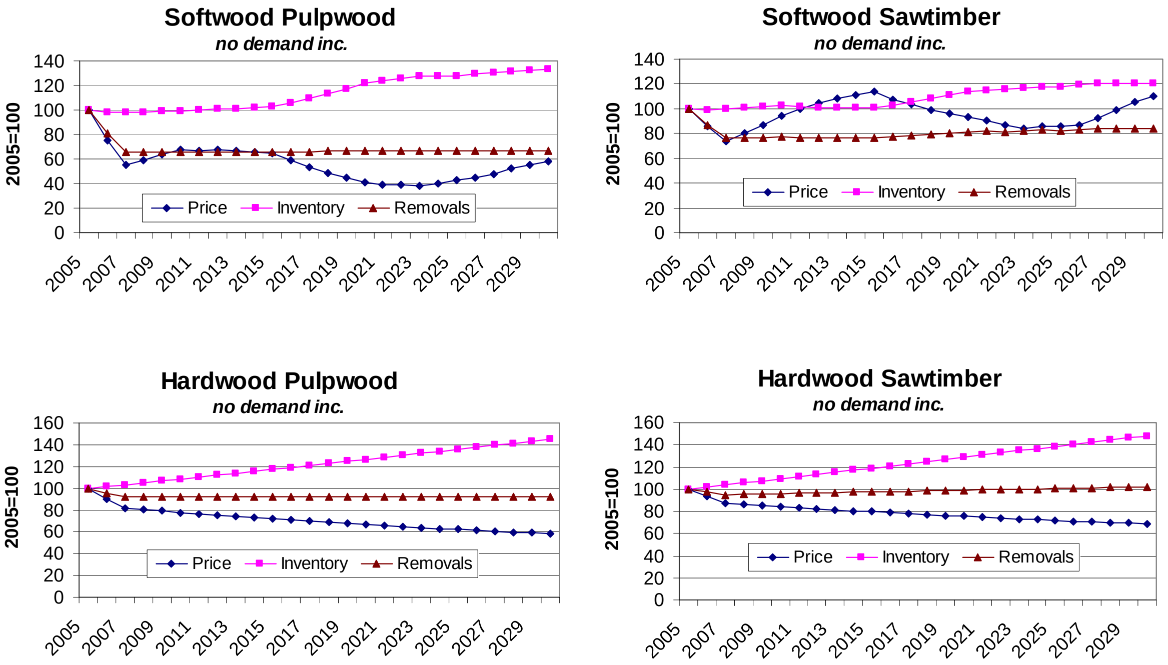

Figure 4.1 The projection of roundwood markets, inventory, and removals with no demand increase for forest biomass in Tennessee through 2030.

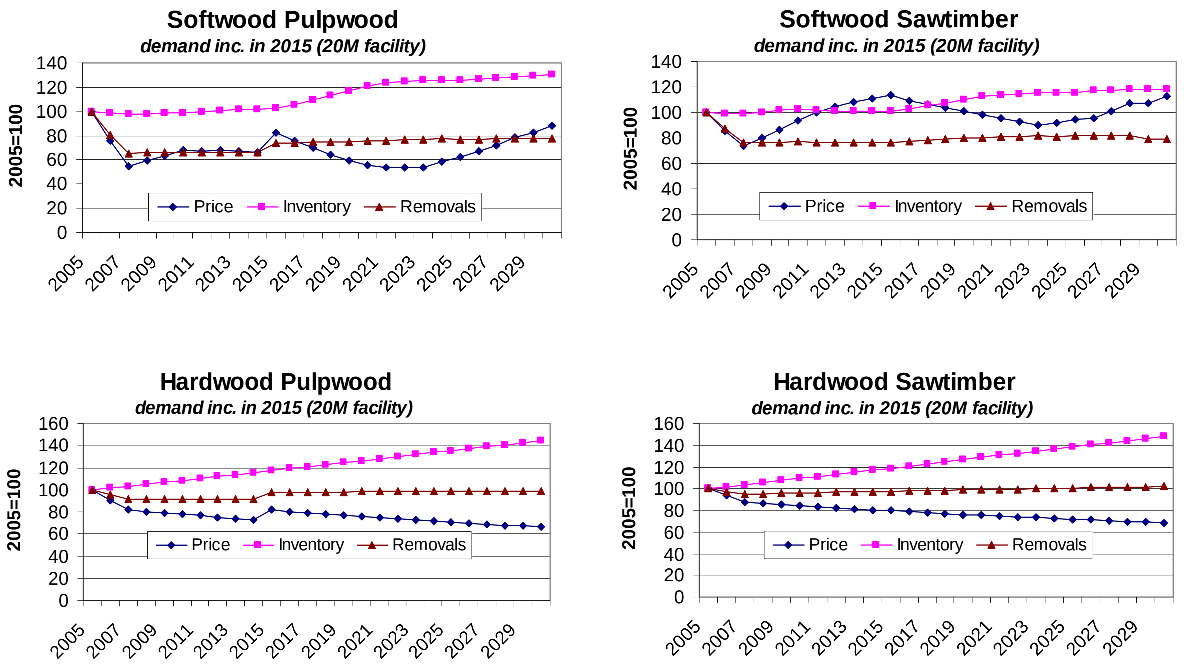

Figure 4.2 Roundwood market effects of an additional demand for pulpwood for a 20M biorefinery facility being built in 2015 in Tennessee.

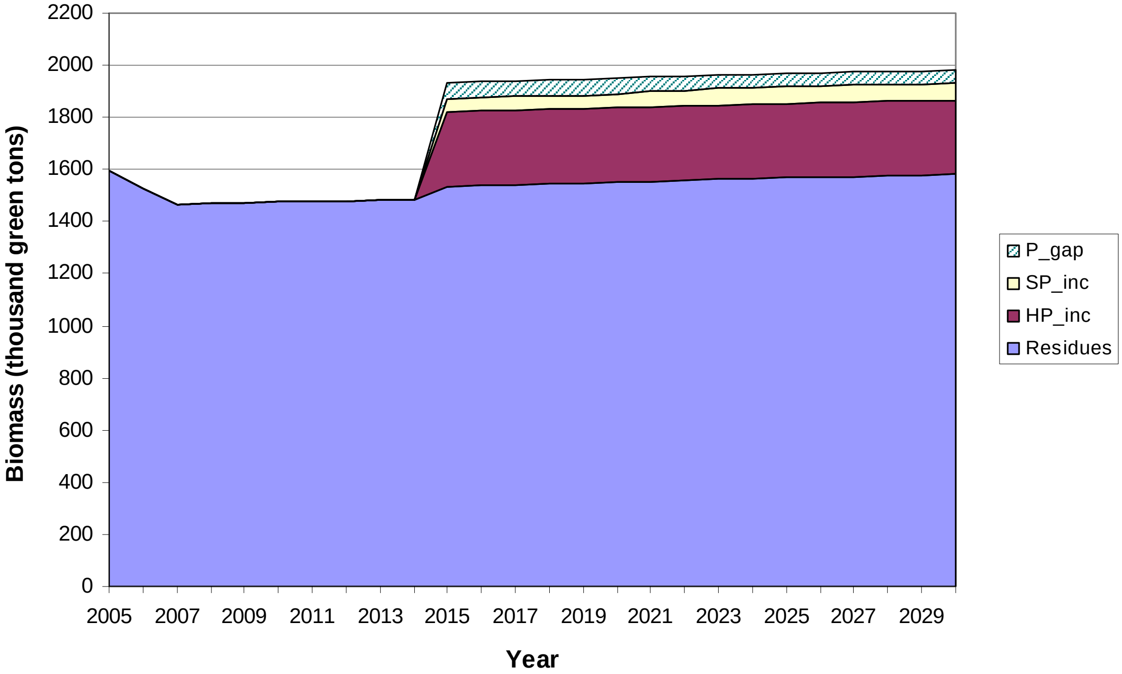

Figure 4.3. Harvesting residues and pulpwood supply for bioenergy production, and the shortfall of pulpwood supply with an annual demand for a 20M biorefinery facility being built in 2015 in Tennessee.

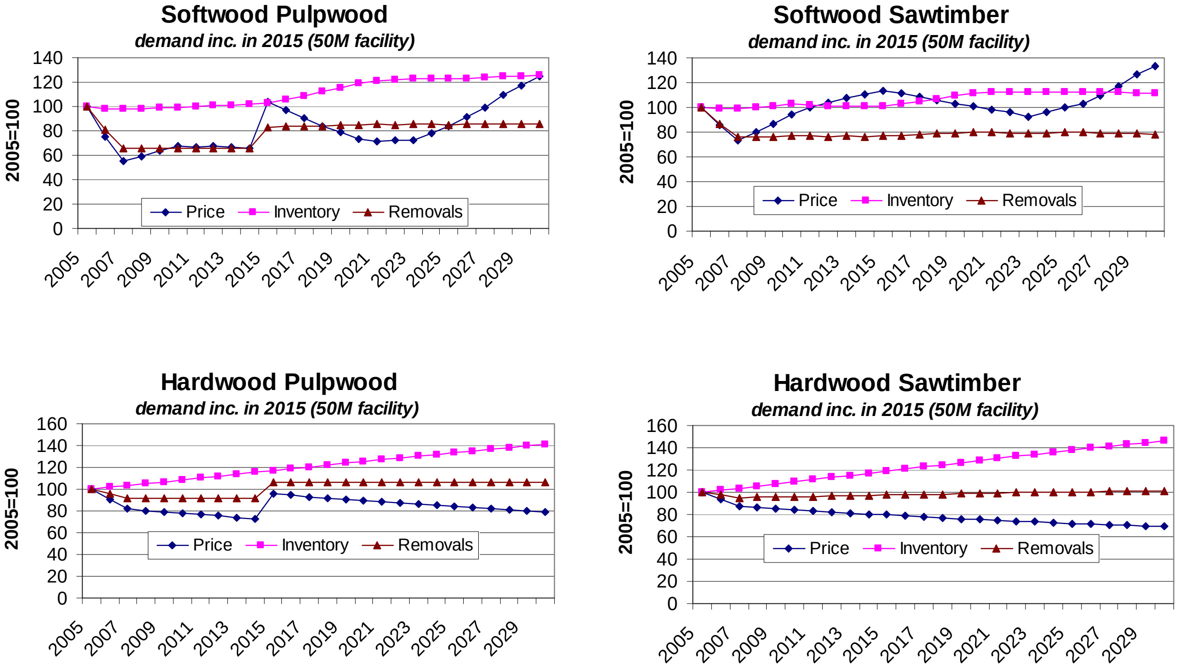

Figure 4.4 Roundwood market effects of an additional demand for pulpwood for a 50M biorefinery facility being built in 2015 in Tennessee.

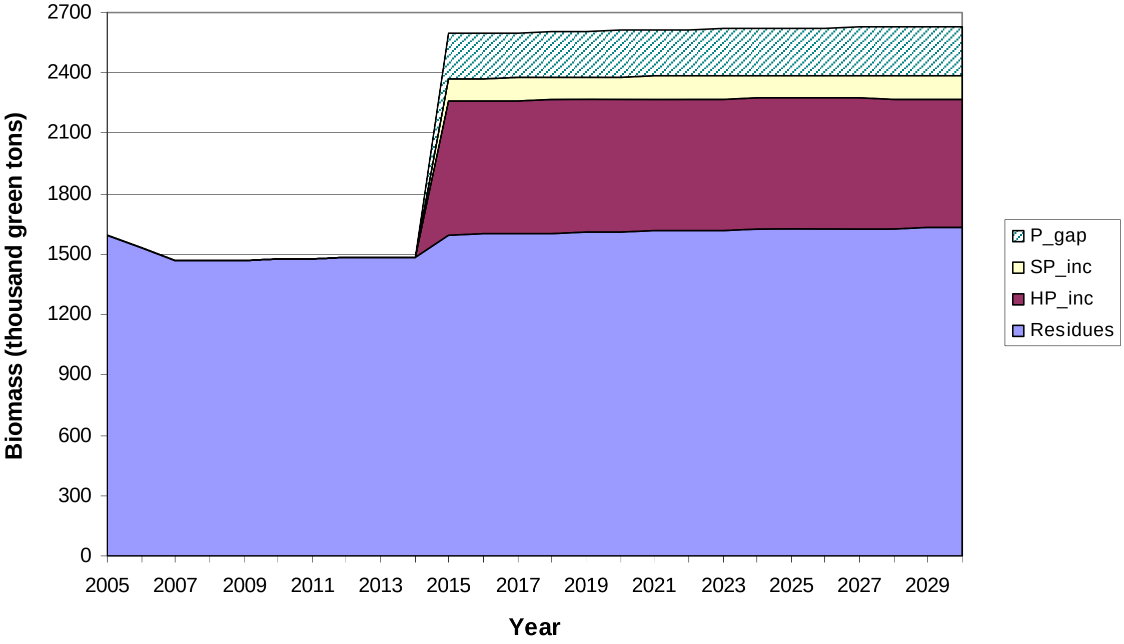

Figure 4.5 Harvesting residues and pulpwood supply for bioenergy production, and the shortfall of pulpwood supply with an annual demand for a 50M biorefinery facility being built in 2015 in Tennessee.

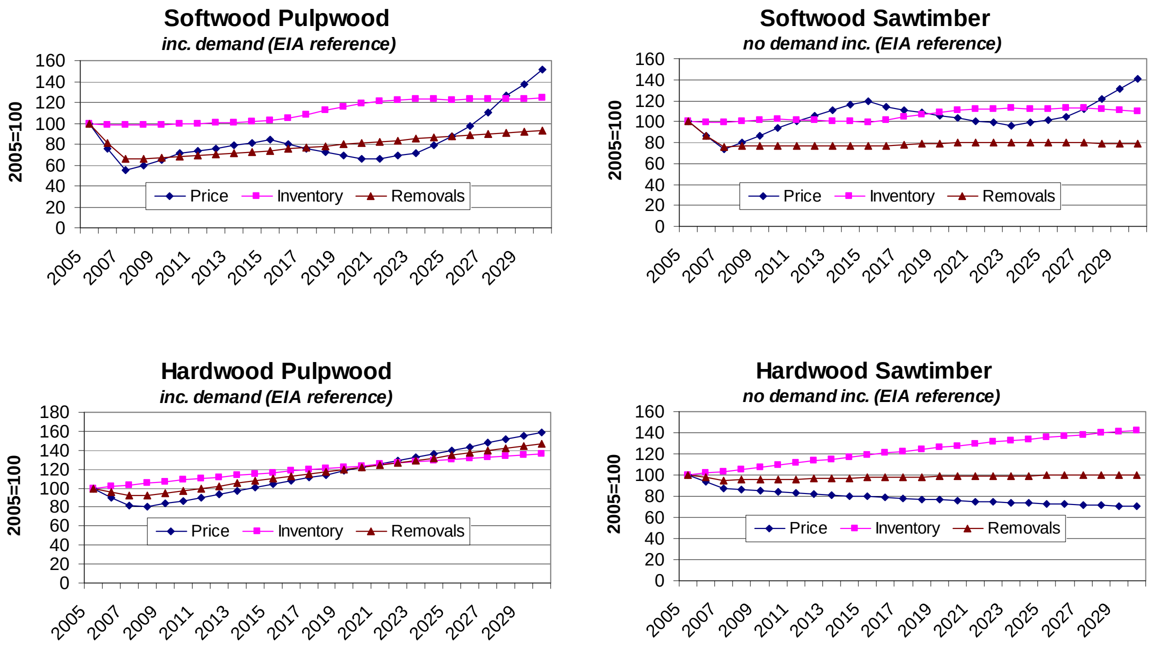

Figure 4.6 Roundwood market effects of the third scenario (similar to the EIA reference case) in Tennessee (annual additional demand of 155,300 green tons consists of 5% softwood pulpwood and 95% hardwood pulpwood).

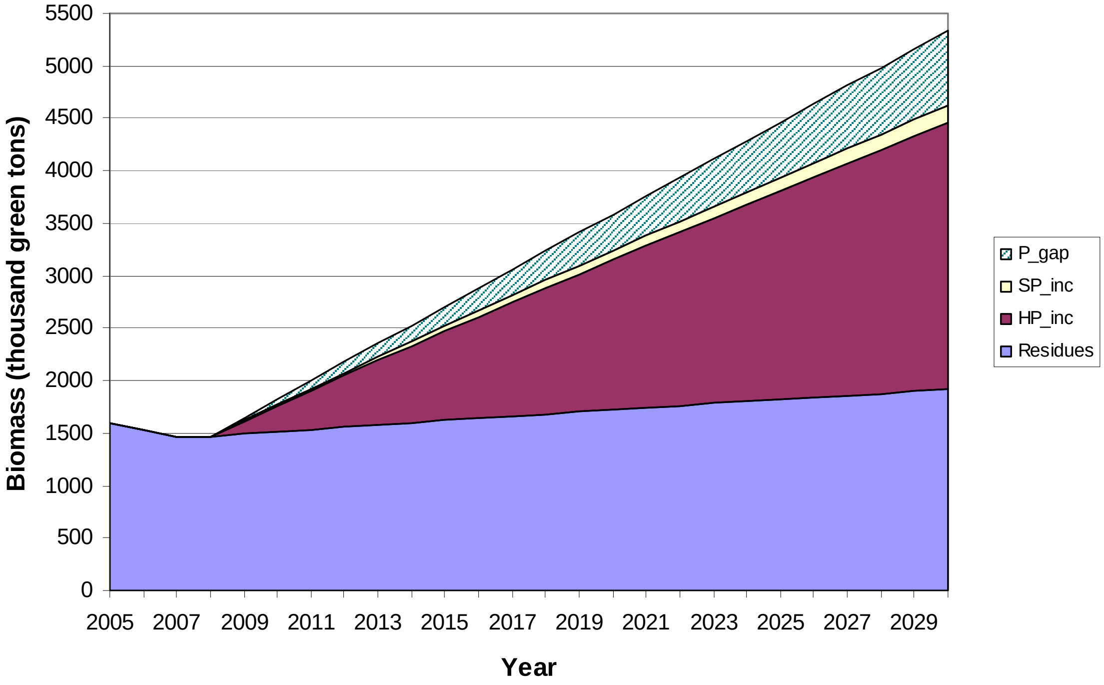

Figure 4.7 Harvesting residues and pulpwood supply for bioenergy production, and the shortfall of pulpwood supply in Tennessee of the third scenario (similar to the EIA reference case: annual additional demand of 155,300 green tons consists of 5% softwood pulpwood and 95% hardwood pulpwood).

Chapter 5

Effect of Bioenergy Policies on the Optimal Forest Stock and Harvest

Abstract

Various governmental policies have been implemented to spur the utilization of small diameter wood for bioenergy production. Much of this wood is likely to come from thinning and logging residues. This paper explores how government subsidies for thinning materials and logging residues for bioenergy production will affect optimal values of forest stock, harvest, silvicultural effort, and rotation length. The results reveal that incentives for using thinning materials and logging residues will have similar effects on the optimal steady state forest stock, harvest, and silvicultural efforts in the long-run. However, the magnitude of the effects differs. Governmental subsidies for forest biomass will increase the long-run silvicultural effort of landowners who are not concerned with the non-market benefits of the forest stock. The other effects on forest stock level, harvest, and silvicultural practices are ambiguous or depend on specific situations. Therefore, how government incentives affect the sustainability of natural resources can be diverse.

Keyword: government subsidies, logging residues, marginal benefit, sustainable forest management, thinning

Introduction

Renewable energy policies have promoted the use of woody biomass as an alternative source for bioenergy production since the 1970s (e.g., the Public Utility Regulatory Policies Act of 1978 and North Carolina General Statutes §§ 105-129.15 et seq.). Recently, the utilization of forest biomass for bioenergy has drawn an increasing amount of attention due to its potential environmental and economic benefits. A variety of federal and state governmental policies have been established to encourage the removal of forest materials for bioenergy production. Various pieces of legislation address the challenges of the high costs of harvesting, handling, and transporting biomass. These policy instruments can be categorized as financial incentives, rules and regulations, and public service programs (Cubbage et al. 1993; Becker and Lee 2008).

These policies aim to establish a wood-energy industry and promote demand for woody biomass (Aguilar and Saunders 2010). Currently, most of the focus is on utilizing small diameter trees from thinning and logging residues. Thinning is the selective removal of trees to reduce competition in overcrowded forests. The trees removed by thinning are also referred to as thinning materials or thinning. Logging residues are the unused portions of trees cut by logging and left in the forest.[2] As the technology for converting woody biomass into energy matures, it is likely that timber will be harvested for bioenergy production if the benefits from bioenergy utilization exceed the timber and other non-timber benefits. Bioenergy policies will also have substantial effects on forest management. How these policies are likely to affect the sustainability of forest resource management is an important issue and has not yet been adequately investigated. Similarly, the effects of these policies on the long-run potential timber and biomass supply also need to be examined.

Traditional rotation analysis has examined the impact of using forest biomass for bioenergy on the optimal harvest age. The results suggest that the inclusion of the value of forest removals for bioenergy into the traditional Faustmann model will shorten optimal rotation length (Bjørnstad and Skonhoft 2002). This finding provides a general principle for managing even-aged plantations. However, the result may be of limited value for decisions regarding harvesting timber and biomass from uneven-aged or natural forests because of the

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[2] The terms forest biomass, woody biomass, and biomass are used interchangeably in this paper to refer to thinning materials and logging residues.

importance of non-timber benefits and sustainability concerns in such circumstances.

More generally, optimal forest stock and harvest are important not only to the provision of timber and non-timber services, but also as indicators of sustainability. Previous research has used a dynamic optimization approach to model forest resource decision and policy problems. These studies have generated optimal steady state harvest levels, both with and without non-timber benefits in the model, and have investigated how economic and financial factors impact optimal stock and harvest levels (Anderson 1976; Snyder and Bhattacharyya 1990; Gan et al. 2001). Gan et al. (2001) demonstrated that the optimal steady state stock will not exceed the maximum sustainable yield (MSY) stock, if timber value alone is considered. Their results also suggest that the addition of non-timber benefits will increase the optimal steady state forest stock. Thus, a large ratio of non-timber benefits to timber benefits can help conserve forest resources.

The objective of this paper is to explore the potential impact of bioenergy policies on the optimal forest stock, harvest, and silvicultural effort. This paper extends the literature by incorporating the biomass benefits into theoretical dynamic optimization models of forest management. Government subsidies and the market and non-market benefits (NMB) associated with the use of forest thinnings and logging residues for bioenergy production are incorporated in the models and then, the optimal steady state forest stock, rotation length, and harvest are examined. Analyses of the impact of governmental subsidies on the optimal steady state forest stock and harvest follow. Some policy implications of the results are then discussed.

Methodology and theoretical approach

Forests not only have timber values but also provide a number of ecosystem services such as soil conservation, habitat for a wide variety of animals and plants, and carbon sequestration. Many previous optimal rotation or forest stock and harvest studies include merely the value of timber harvested (h) for market benefits ($V(h)$) and conservation values of the forest stock as NMB ($U(x)$) in a generic model. To explore the effect of government incentives on woody biomass, this study incorporates the market and non-market benefits provided by two other forest outputs: thinnings and logging residues.

The first step in developing the model is to understand the underlying biological growth relationships. Thinning is an important management activity that is undertaken to increase the growth rate of the remaining trees and to improve forest health (Baldwin et al. 1989; Franklin et al. 2009). Thinning may also reduce the threat of wildfire and create better habitats for some wildlife compared with overstocked forests. In this regard, the NMB of thinnings (B) may be a strictly concave function, i.e., $U'(B) > 0$ and $U''(B) < 0$, when the extent of thinning is less than or equal to the optimal level; if thinnings are greater than the optimal amount, the utility of thinning will decrease as thinnings increase, i.e., $U'(B) < 0$. The NMB are also dependent on the level of forest stock (x), denoted by $U(x, B)$. In addition, regional markets may exist for thinnings in the form of wood processing factories and bioenergy plants. Hence, thinnings also generate market benefits, denoted by $V(B)$.

Logically, logging residues and timber will be harvested simultaneously. According to previous research (Bjørnstad and Skonhoft 2002), the quantities of logging residues (L) can be considered as a function of timber (h) harvested or $L = L(h) = L(h(t))$ with $L(0) = 0$, $L'(h) > 0$, and $L''(h) < 0$, so that L is a strictly concave function. Considering that only a proportion (α) of logging residues will be recovered for bioenergy production, the market benefit of logging residues received is denoted by $V(L^r)$, where $L^r = \alpha(t)L(h(t))$. Therefore, market benefits received are a function of the amount of timber harvested, logging residues recovered, and thinnings denoted by $V(h, L^r, B)$.

In addition to monetary value, logging residues can also provide NMB. Logging residues left in the forest may provide services such as reducing soil erosion, improving watershed condition, and conserving biodiversity (Neary 2002; Luebbeke 2006; Jonsell 2008). Thus, NMB also depend on the amount of logging residues that remain on site L^o, where $L^o = L - L^r = (1-\alpha)L = (1-\alpha(t))L(h(t))$. The NMB received by many private forest landowners and the general public can, thus, be denoted by $U(x, L^o, B)$.

Social Planners' Problem

Based on a unit area of forestland, a generic model is developed for social planners assuming their forest management goal is to maximize the present value of net market and NMB over an infinite time horizon. To be consistent with previous work, silvicultural effort (E) and land rent (r) are incorporated into the model as the costs of forest production. Assuming the values of timber, thinnings, and logging residues are net benefits, the costs of harvesting have been implicitly included in the model. Forest production is subject to the constraints of forest stock and silvicultural efforts. The current value Hamiltonian can be formulated as follows:

$$\begin{aligned} &\widetilde{H}[x(t),h(t),E(t),B(t),\alpha(t);\mu(t)] \\ &= V[h(t),L^r(t),B(t)] + U[x(t),L^o(t),B(t)] - wE(t) - r \qquad (1) \\ &+ \mu(t)\{g[x(t),E(t)] - h(t) - B(t)\} \end{aligned}$$

where $x(t)$, $h(t)$, and $B(t)$ are forest stock level, timber harvest level, and the amount of thinning at time t, respectively; $\alpha(t)$ is the proportion of logging residues recovered for bioenergy production; *E(t)* is the silvicultural effort at time *t*; *w* is the per unit cost of silvicultural activities; and *r* the forestland rent. Forest growth *g(·)* is a function of the level of forest stock and silvicultural effort. It is generally modeled as a logistic or quadratic function and therefore is assumed continuous, twice differentiable, and strictly quasiconcave. To ensure that a unique interior optimum exists, *V(·)* is assumed to be continuous, twice differentiable, increasing, and quasiconcave. It is not necessary that *U(·)* be increasing or quasiconcave because it will not influence the optimal steady state results in this study (Gan et al. 2001).

The equation of motion, $\dot{x} = g[x(t), E(t)] - h(t) - B(t)$, implies that the rate of change of the forest stock is the difference between the net growth and the removals of timber and thinning materials. Thinning in period *t* affects growth in period *t+1* through changing of the level of the forest stock. The initial and non-negativity constraints for the forest stock are $x(0) = x_0$ and $x(t), h(t), B(t), E(t), \alpha(t) \geq 0$. The Hamitonian and the two constraints comprise a dynamic optimization problem with one state variable *x(t)* and four control variables, *h(t)*, *B(t)*, *E(t)* and *α(t)*.

The co-state variable is *μ(t)* (i.e. $\lambda(t)e^{\delta t}$), the dynamic current value shadow price of the forest stock *(x)*. This variable reflects how an incremental change in forest stock would affect market and NMB over the remainder of the time horizon. Maximizing the current value Hamiltonian yields problem requires the first-order optimality conditions to hold (Table 5.1):

$$\frac{\partial \widetilde{H}}{\partial h} = V_h + \alpha V_{L^r} L_h + (1-\alpha) U_{L^o} L_h - \mu = 0 \tag{2}$$

$$\frac{\partial \widetilde{H}}{\partial E} = -w + \mu g_E = 0 \tag{3}$$

$$\frac{\partial \widetilde{H}}{\partial \alpha} = V_{L^r} L - U_{L^o} L = 0 \tag{4}$$

$$\frac{\partial \widetilde{H}}{\partial B} = V_B + U_B - \mu = 0 \tag{5}$$

$$\dot{\mu} - \delta\mu = -\frac{\partial \widetilde{H}}{\partial x} = -U_x - \mu g_x \tag{6}$$

Reorganizing Eqs. (3) to (5) provides:

$$w = \mu g_E \tag{7}$$

$$V_{L^r} = U_{L^o} \tag{8}$$

$$V_B + U_B = \mu \tag{9}$$

Substituting Eq. (8) into Eq. (2) and reorganizing it, we have:

$$V_h + U_{L^o} L_h = \mu \tag{10}$$

or

$$V_h + V_{L^r} L_h = \mu \tag{11}$$

Substituting μ, Eq. (9) becomes:

$$V_B + U_B = V_h + V_{L^r} L_h \tag{12}$$

Landowners' Problem

Various policies have been enacted to encourage the removal of forest materials for bioenergy production. Forest landowners may receive monetary benefits from governmental programs. For many family forest landowners who manage their forests for both market and non-market benefits, the benefit maximization problem is a social planner's model plus the monetary benefits received from government for forest biomass utilization. To explore how government incentives on forest biomass impact optimal steady state forest stock and management, subsidy rates for thinning (S^B) and logging residues recovered (S^{L^r}) are incorporated into the model:

$$
\begin{aligned}
&\widetilde{H}[x(t),h(t),E(t),B(t),\alpha(t);\mu(t)] \\
&= V[h(t),L^r(t),B(t)] + S^{L^r}(t)\cdot L^r(t) + S^B(t)\cdot B(t) + U[x(t),L^o(t),B(t)] - wE(t) - r \\
&+ \mu(t)\{g[x(t),E(t)] - h(t) - B(t)\}
\end{aligned}
\tag{13}
$$

Firms and some private landowners do not receive any utility from non-market goods or services provided by the forest stock. However, they may be concerned about the NMB of forest biomass because logging residues on site and thinning can improve forest health. Hence, their forest management goal is to maximize the present value of net market benefits and NMB of logging residues and thinnings over an infinite time horizon. The NMB *U(x)* are excluded from the benefit maximization model. The current value Hamiltonian can then be expressed as:

$$
\begin{aligned}
&\widetilde{H}[x(t),h(t),E(t),B(t),\alpha(t);\mu(t)] \\
&= V[h(t),L^r(t),B(t)] + S^{L^r}(t)\cdot L^r(t) + S_B(t)\cdot B(t) + U[L^o(t),B(t)] - wE(t) - r \\
&+ \mu(t)\{g[x(t),E(t)] - h(t) - B(t)\}
\end{aligned}
\tag{14}
$$

Maximizing landowners' model produces

$$V_h + (V_{L^r} + S^{L^r})L_h = \mu \tag{15}$$

$$V_{L^r} + S^{L^r} = U_{L^o} \tag{16}$$

Eq. (15) indicates that the product of the marginal logging residue produced from harvest and the marginal monetary value of logging residues (i.e., the sum of marginal market benefit and subsidy rate), together with marginal timber benefit, determines the optimal harvest level. These first-order optimality conditions were different from that of social planners' model due to the inclusion of subsidy rates. For social planners, the current value shadow price equals the sum of the marginal timber benefit and the product of the marginal logging residue benefit and the marginal logging residue produced from harvest (Eq. 11).

Though most research assumed fixed logging residue recovery rates to estimate logging residue availability, to maximize the market and non-market benefits from forests, the optimal recovery rate of logging residues should equate the sum of marginal market benefits and subsidy rate for removing logging residues to marginal non-market benefits of logging residues remaining on site (Eq. 16). This optimality condition is also different from that of social planners' model (Eq. 8).

All first-order optimality conditions for landowners' dynamic optimization problems are presented and compared to those of the social planners' problem in Appendix 1. The optimal silvicultural effort equates its marginal cost or price to the current value of its marginal product is the same for all landowners and social planners (Eq. 7). It is also distinct with no biomass benefits in the model. Most other optimality conditions are different from the results of previous study considering no biomass benefits (Gan et al. 2001). These differences indicated that biomass benefits can affect the optimal rotation and the steady state forest stock and harvest.

The optimal paths of the control variables, $B(t)$, $h(t)$, $\alpha(t)$, and $E(t)$ can be found, given functions $V[h(t), L^r(t), B(t)]$, $U[x(t), L^o(t), B(t)]$, $g[x(t),E(t)]$ and values of w, δ, and x_0. In equilibrium, $x(t)$, $B(t)$, $h(t)$, $\alpha(t)$, and $E(t)$ will not change. By setting $\dot{x} = \dot{B} = \dot{h} = \dot{\alpha} = \dot{E} = 0$, the optimal steady state solution (x^*, B^*, h^*, α^*, E^*) can be found. This solution provides useful information on sustainably supply of timber and forest biomass for bioenergy. Through comparative statics analyses, the impact of government incentives on logging residue and thinnings on the level of forest stock, timber harvest, and silvicultural efforts is then investigated.

Optimal steady state forest stock and harvest

Taking the time derivative of Eq. (11), we obtain:

$$V_{hh}\dot{h} + V_{L^r}^2(L\dot{\alpha} + \alpha L_h\dot{h})L_h + V_{L^r}L_{hh}\dot{h} = \dot{\mu} \tag{17}$$

At the equilibrium $\dot{h} = \dot{\alpha} = 0$. Substituting the zero values into Eq. (17) produces $\dot{\mu} = 0$.

Substituting Eq. (11) and $\dot{\mu} = 0$ into Eq. (6) yields:

$$(V_h + V_{L^r}L_h)(\delta - g_x) - U_x = 0 \tag{18}$$

Rearranging, Eq. (18) becomes:

$$\delta = g_x + \frac{U_x}{V_h + V_{L^r}L_h} \tag{19}$$

In the same way, we can obtain Eq. (20) for landowners who receive utilities from non-market goods of the forest stock:

$$\delta = g_x + \frac{U_x}{V_h + (V_{L^r} + S^{L^r})L_h} \tag{20}$$

For landowners who do not care about non-market goods or services of the forest stock, we have:

$$\delta = g_x \tag{21}$$

Eq. (21) is the same as that of considering only timber value. It does not reveal how the marginal market logging residue benefit or subsidy rate affect the optimal rotation length and optimal steady state forest stock and harvest. As discussed by Gan et al. (2001), the marginal growth of the forest stock should equal the discount rate at the optimal steady state. When the discount rate approaches zero, the optimal steady state forest stock and harvest approach the MSY stock and harvest which can only occur when $g_x = 0$. However, when $g_x > 0$, the optimal forest stock and harvest will be less than the MSY stock and harvest. Since $g_x > 0$ before the forest stock (x) reaches maximum level, the optimal rotation length will be shorter than the age associated with MSY, which is consistent with many studies (Hyde 1980; Chang 1983; Gan et al. 2001).

Eq. (19) suggests that the optimal rotation length for social planners should be determined by equating the discount rate to the sum of the marginal growth of the forest stock and the ratio of the marginal non-timber benefit to the marginal timber and logging residue benefits. Excluding the term of the marginal logging residue benefit, it is the same as the results ($\delta = g_x + \frac{U_x}{V_h}$) from the model without biomass benefits (Gan et al. 2001). For a quasiconcave forest growth function, it indicates a shorter rotation length because $\frac{U_x}{V_h + V_{L^r} L_h} < \frac{U_x}{V_h}$ results in a bigger g_x at a certain discount rate.

Eq. (20) reveals how marginal market benefits and the subsidy rate of logging residues will influence the optimal rotation length, as well as the optimal steady state forest stock and timber harvest. At the optimal steady state, g_x could be positive, negative, or zero depending on the sign of $\delta - \frac{U_x}{V_h + (V_{L^r} + S^{L^r})L_h}$. When $\delta = \frac{U_x}{V_h + (V_{L^r} + S^{L^r})L_h}$, $g_x = 0$. Because $g(\cdot)$ is quasiconcave, the optimal forest stock and harvest reach the MSY stock and the MSY, respectively. If g_x is negative (i.e., $\delta - \frac{U_x}{V_h + (V_{L^r} + S^{L^r})L_h} < 0$), the optimal forest stock will exceed the MSY stock and the optimal harvest of timber will be less than the MSY. In case that $\delta > \frac{U_x}{V_h + (V_{L^r} + S^{L^r})L_h}$, g_x is positive. The optimal forest stock and harvest will be less than the MSY stock and the MSY, respectively.

At a given discount rate, increases in the marginal non-market benefit (U_x) or decreases in the subsidy rate for logging residues, the marginal timber (V_h), or logging residue benefit (V_{L^r})

will extend the optimal rotation length for landowners concerned with the NMB of the forest stock. The change in the optimal steady state forest stock level and the optimal harvest will depend on the sign of g_x. If g_x is positive, the optimal forest stock will approach the MSY and the optimal harvest level will be higher.

For social planners, substituting Eq. (12) into Eq. (19) and rearranging it provides:

$$\delta = g_x + \frac{U_x}{V_B + U_B} \tag{22}$$

Eq. (22) provides an interesting relationship between the discount rate, the marginal growth rate of forest stock, and the ratio of marginal non-timber benefit to the marginal market and non-market benefit of thinning. Specifically, optimal thinning should equate the discount rate to the marginal growth of the forest plus the ratio of marginal non-market benefit of the forest stock to the total marginal benefits of thinning. At a given discount rate, decreases in the marginal market (V_B) or non-market thinning benefit (U_B) will extend the optimal rotation length. The change in the optimal steady state forest stock level and the optimal harvest will depend on the sign of g_x.

In the same way, we can obtain Eq. (23) for all landowners who are concerned about NMB of the forest stock:

$$\delta = g_x + \frac{U_x}{V_B + S^B + U_B} \tag{23}$$

It suggests that, at a given discount rate, increases in the subsidy rate for thinnings will shorten the optimal steady state rotation length. In case g_x is positive, the optimal forest stock will become far less than the MSY and the optimal harvest level will be reduced.

Impact of subsidy rates and marginal NMB of forest biomass

The impact of changes in subsidy rates and marginal NMB of forest biomass on the optimal steady state forest stock, harvest of timber and biomass, and silvicultural effort can be investigated through comparative statics analyses. For the sake of simplicity, it is assumed that the marginal timber benefit (V_h), the marginal market logging benefits (V_{L^r}), the marginal thinning benefits (V_B and U_B), and the marginal non-market benefit (U_x) are constant, positive values of P, P_L, P_B, ρ_B, and ρ_x, respectively.

In equilibrium, $\dot{x} = 0$. The equation of motion then becomes:

$$g[x(t), E(t)] - h(t) - B(t) = 0 \tag{24}$$

Substituting Eq.(15) into Eq.(7) and rearranging, we obtain:

$$g_E = \frac{w}{(V_h + (V_{L^r} + S^{L^r})L_h)} \tag{25}$$

Rearranging Eq.(20), provides:

$$g_x = \delta - \frac{U_x}{V_h + (V_{L^r} + S^{L^r})L_h} \tag{26}$$

Eqs. (24), (25), and (26) comprise an implicit equations system from which the steady state solution can be found for landowners who concerns non-market goods or services. Applying the implicit function theorem to these three equations, we have:

$$g_x dx + g_E dE - dh - dB = 0 \tag{27}$$

$$(P + (P_L + S^{L^r})L_h)g_{Ex}dx + g_{EE}dE = dW - g_E(dP + L_h dP_L + L_h dS^{L^r}) \tag{28}$$

$$g_{xx}dx + g_{xE}dE = d\delta - \frac{(P + (P_L + S^{L^r})L_h)d\rho - \rho(dP + L_h dP_L + L_h dS^{L^r})}{(P + (P_L + S^{L^r})L_h)^2} \tag{29}$$

The simultaneous equation system can then be written as:

$$\begin{pmatrix} g_x & -1 & g_E \\ (P+(P_L+S^{L^r})L_h)g_{Ex} & 0 & (P+(P_L+S^{L^r})L_h)g_{EE} \\ g_{xx} & 0 & g_{xE} \end{pmatrix}\begin{pmatrix} dx \\ dh \\ dE \end{pmatrix} = \begin{pmatrix} dB \\ dW - g_E dP - g_E L_h dP_L - g_E L_h dS^{L^r} \\ d\delta - \dfrac{(P+(P_L+S^{L^r})L_h)d\rho - \rho(dP + L_h dP_L + L_h dS^{L^r})}{(P+(P_L+S^{L^r})L_h)^2} \end{pmatrix} \tag{30}$$

To explore the effects of changes in thinning subsidies, we substitute Eq. (16) into Eq. (7) which provides:

$$(P_B + S^B + \rho_B)g_E = W \tag{31}$$

Rearranging Eq.(23), we obtain:

$$g_x = \delta - \frac{U_x}{(P_B + S^B + \rho_B)} \tag{32}$$

Applying the Implicit Function Theorem to Eqs. (27), (31), and (32), we have:

$$\begin{pmatrix} g_x & -1 & g_E \\ (P_B+S^B+\rho_B)g_{Ex} & 0 & (P_B+S^B+\rho_B)g_{EE} \\ g_{xx} & 0 & g_{xE} \end{pmatrix}\begin{pmatrix} dx \\ dh \\ dE \end{pmatrix} = \begin{pmatrix} dB \\ dW - g_E dP_B - g_E dS^B - g_E d\rho_B \\ d\delta - \dfrac{(P_B+S^B+\rho_B)d\rho - \rho(dP_B + dS^B + d\rho_B)}{(P_B+S^B+\rho_B)^2} \end{pmatrix} \tag{33}$$

In the same way, we can obtain the simultaneous equation system for firms or landowners who are not concerned with the NMB of the forest stock. They are:

$$\begin{pmatrix} g_x & -1 & g_E \\ (P+(P_L+S^{L^r})L_h)g_{Ex} & 0 & (P+(P_L+S^{L^r})L_h)g_{EE} \\ g_{xx} & 0 & g_{xE} \end{pmatrix}\begin{pmatrix} dx \\ dh \\ dE \end{pmatrix} = \begin{pmatrix} dB \\ dW - g_E dP - g_E L_h dP_L - g_E L_h dS^{L^r} \\ d\delta \end{pmatrix} \tag{34}$$

and

$$\begin{pmatrix} g_x & -1 & g_E \\ (P_B+S^B+\rho_B)g_{Ex} & 0 & (P_B+S^B+\rho_B)g_{EE} \\ g_{xx} & 0 & g_{xE} \end{pmatrix}\begin{pmatrix} dx \\ dh \\ dE \end{pmatrix} = \begin{pmatrix} dB \\ dW - g_E dP_B - g_E dS^B - g_E d\rho_B \\ d\delta \end{pmatrix} \tag{35}$$

Let

$$A = \begin{pmatrix} g_x & -1 & g_E \\ (P+(P_L+S^{L^r})L_h)g_{Ex} & 0 & (P+(P_L+S^{L^r})L_h)g_{EE} \\ g_{xx} & 0 & g_{xE} \end{pmatrix} \tag{36}$$

So,

$$|A| = (P+(P_L+S^{L^r})L_h)\begin{vmatrix} g_{Ex} & g_{EE} \\ g_{xx} & g_{xE} \end{vmatrix} \tag{37}$$

Since g(·) is strictly quasiconcave, |A| < 0.

To examine the effect of variation in subsidy rate for logging residues (S_L) alone on the optimal steady state stock, harvest, and silvicultural effort of landowners who are concerned with the NMB of the forest stock, set $d\alpha = dW = dP = dP_L = dP_B = d\rho = d\rho_B = dS_B = d\delta = 0$ in Eq. (30). Eq. (30) can then be solved using Cramer's Rule:

$$\frac{\partial x^*}{\partial S^{L^r}} = -\frac{L_h}{|A|}\cdot[g_E g_{xE} + \frac{\rho g_{EE}}{P+(P_L+S^{L^r})L_h}] \tag{38}$$

$$\frac{\partial h^*}{\partial S_L} = \frac{L_h}{|A|} \cdot [g_E{}^2 g_{xx} - g_x g_E g_{xE} - \frac{\rho(g_x g_{EE} - g_E g_{Ex})}{P + (P_L + S^{L^r})L_h}] \qquad (39)$$

$$\frac{\partial E^*}{\partial S_L} = \frac{L_h}{|A|} \cdot [g_E g_{xx} + \frac{\rho g_{Ex}}{P + (P_L + S^{L^r})L_h}] \qquad (40)$$

In the same way, the effect of changes in subsidy rate for thinnings (S_B) can be solved.

$$\frac{\partial x^*}{\partial S_B} = -\frac{1}{|A|} \cdot [g_E g_{xE} + \frac{\rho g_{EE}}{P_B + S^B + \rho_B}] \qquad (41)$$

$$\frac{\partial h^*}{\partial S_B} = \frac{1}{|A|} \cdot [g_E{}^2 g_{xx} - g_x g_E g_{xE} - \frac{\rho(g_x g_{EE} - g_E g_{Ex})}{P_B + S^B + \rho_B}] \qquad (42)$$

$$\frac{\partial E^*}{\partial S_B} = \frac{1}{|A|} \cdot [g_E g_{xx} + \frac{\rho g_{Ex}}{P_B + S^B + \rho_B}] \qquad (43)$$

The results are presented and compared in Table A.2 for both types of landowners (see Appendix 2). The effects of the changes in marginal NMB of thinning (ρ_B) for landowners who are concerned about the NMB of the forest stock were also analyzed to compare with the effect of changes in subsidy rates for thinnings. For firms or landowners who have no interest in non-market goods or services of the forest stock, the effect of marginal NMB is zero.

Proposition 1. The effect of increases in marginal subsidy rates for thinnings and for logging residues on the optimal steady state forest stock, harvest, and silvicultural effort are in the same direction. However, the intensity of the effect of changing subsidy for thinnings, is larger, given that L_h is less than one.

Proof: From eqs. (38) and (41), the difference of the intensity between the effect of increases in marginal subsidy rates for thinnings and for logging residues on the optimal steady state forest stock can be written as:

$$\left|\frac{\partial x^*}{\partial S^B}\right| - \left|\frac{\partial x^*}{\partial S^{L^r}}\right| = \left|-\frac{1}{|A|} \cdot [g_E g_{xE} + \frac{\rho g_{EE}}{P_B + S^B + \rho_B}]\right| - \left|-\frac{L_h}{|A|} \cdot [g_E g_{xE} + \frac{\rho g_{EE}}{P + (P_L + S^{L^r})L_h}]\right| \qquad (44)$$

From the first-order optimality conditions, we have $P + (P_L + S^{L^r})L_h = \mu = P_B + S^B + \rho_B$,

Thus,

$$\left|\frac{\partial x^*}{\partial S^B}\right| - \left|\frac{\partial x^*}{\partial S^{L^r}}\right| = \left|-\frac{1}{|A|}\cdot[g_E g_{xE} + \frac{\rho g_{EE}}{P_B + S^B + \rho_B}]\right| - \left|-\frac{L_h}{|A|}\cdot[g_E g_{xE} + \frac{\rho g_{EE}}{P_B + S^B + \rho_B}]\right| \qquad (45)$$

Since the logging residues produced from harvesting generally increase at a rate lower than the timber harvested, the marginal logging residue (L_h) is greater than zero and less than one. Hence,

$$\left|\frac{\partial x^*}{\partial S^B}\right| - \left|\frac{\partial x^*}{\partial S^{L^r}}\right| = (1 - L_h)\left|-\frac{1}{|A|}\cdot[g_E g_{xE} + \frac{\rho g_{EE}}{P_B + S^B + \rho_B}]\right| > 0 \qquad (46)$$

In the same way, it can be shown that the magnitude of the effects of changing subsidy for thinning on the optimal steady state harvest and silvicultural effort will be greater than that for logging residues. This proposition applies to all landowners regardless of their concern about the NMB of the forest stock.

Assuming reasonably g_E is positive, an increase in subsidy rate for logging residues or thinnings will increase the silvicultural effort of firms and landowners who are not concerned about NMB of the forest stock. Other signs of the results, however, are ambiguous. They depend on the relationship between silvicultural effort and the forest stock, and the sign of g_x. The determination of the effects of variation in subsidy rates for logging residues and thinnings on the optimal steady state stock, harvest, and silvicultural effort for specific cases are shown in Table 5.1. The effects of the changes in marginal NMB of thinning are exactly the same as those of the variation in subsidy rates for thinnings.

Proposition 2. When E and x are substitutes, the effects of the increases in subsidy rates for forest biomass on the optimal steady state forest stock or silvicultural effort are similar for all landowners. However, the magnitudes of the effects are greater for landowners who are concerned about the NMB of the forest stock than those who are not.

Proof: The difference of the effect of increases in marginal subsidy rates for thinnings between the two types of landowners can be written as:

$$\left|\frac{\partial x^*}{\partial S^{L^r}}\right|^{NMB} - \left|\frac{\partial x^*}{\partial S^{L^r}}\right|^{0} = \left|-\frac{L_h}{|A|}\cdot\left[g_E g_{xE} + \frac{\rho g_{EE}}{P+(P_L+S^{L^r})L_h}\right]\right| - \left|-\frac{L_h}{|A|}\cdot g_E g_{xE}\right| \tag{47}$$

When E and x are substitutes, g_{xE} is negative and the NMB term ($\frac{\rho g_{EE}}{P+(P_L+S^{Lr})L_h}$) has the same sign with other terms ($g_E g_{xE}$) in the results. The NMB term adds to the magnitude of the effects of subsidy rates on the optimal steady state solution. Therefore,

$$\begin{aligned}\left|\frac{\partial x^*}{\partial S^{L^r}}\right|^{NMB} - \left|\frac{\partial x^*}{\partial S^{L^r}}\right|^{0} &= \left(\left|-\frac{L_h}{|A|}\cdot g_E g_{xE}\right| + \left|-\frac{L_h}{|A|}\cdot\frac{\rho g_{EE}}{P+(P_L+S^{L^r})L_h}\right|\right) - \left|-\frac{L_h}{|A|}\cdot g_E g_{xE}\right| \\ &= \left|-\frac{L_h}{|A|}\cdot\frac{\rho g_{EE}}{P+(P_L+S^{L^r})L_h}\right| > 0\end{aligned} \tag{48}$$

In the same way, it can be shown that increasing forest biomass subsidy will have a greater impact on the optimal forest stock and silvicultural efforts for landowners who are concerned about the NMB of the forest stock than those who are not.

An increase in subsidy rate for logging residues or thinnings will decrease the optimal steady state forest stock and increase the optimal silvicultural effort. Mathematically, the effect of an increase in subsidy rates for forest biomass on the optimal harvest is positive for all firms and landowners, when g_x is negative. However, $g_x = \delta$ cannot be negative for landowners concerning only monetary benefits. Hence, the long-run harvest will increase with a rise in subsidy rates for forest biomass for landowners concerned with NMB of the forest stock. The effect will be ambiguous for firms or landowners who are not.

When E and x are complements, g_{xE} is positive and the NMB terms have the opposite sign with other terms in the results. The effects of the variation in subsidy rates for landowners who are concerned with the NMB from forests depend on the magnitude of those terms and are, therefore, ambiguous. For firms or landowners who are not interested in non-market goods or services of the forest stock, a rise in subsidy rate for logging residues or thinnings will result in an increase in the optimal forest stock and silvicultural effort. When g_x is positive, the long-run harvest will also increase.

Discussion and Conclusion

Various governmental policies have been implemented to spur the utilization of woody biomass for bioenergy production through improving biotechnology and addressing the challenges of using forest biomass. These policies can directly or indirectly affect forest management. First, the additional monetary benefit of government subsidies can influence forest management. Second, increases in the future demand for forest-derived biomass for energy production are also likely to affect forest management. Given that most woody biomass policies encourage the use of small diameter wood; this analysis considered market and non-market benefits and government subsidies for thinning and logging residues in the dynamic optimization model to explore how it will impact forest stock level, harvest levels, optimal rotation length, and silvicultural effort.

For firms and landowners the sum of the marginal timber benefit and the product of the marginal logging residue benefit and the marginal logging residue produced from harvest equal the current-value shadow price of the forest stock at the optimal harvest level (Eqs. 11 and 15). This is different from the social planners' optimal solution, due to the inclusion of the government subsidy. The addition of forest biomass benefits shortens the optimal rotation length. In other words, decreases in subsidy rates or the marginal market benefits of forest biomass relative to the marginal non-market benefit of the forest stock are likely to extend the optimal rotation length for landowners interested in the NMB of the forest stock.

Variations in the subsidy rate for logging residues or thinnings will have similar directional effects on the optimal steady state forest stock level, optimal harvest, and silvicultural effort. However, changes in the subsidy rate for thinnings will have a greater impact on forest management. The effect of forest biomass subsidy will depend on the sign of marginal growth of forest stock (g_x) and the relationship between the forest stock and silvicultural effort. When silvicultural effort and forest stock are substitutes, an increase in the subsidy rate for forest biomass will decrease the long-run harvest forest stock and increase the optimal silvicultural effort for all landowners. The optimal harvest will increase with a rise in subsidy rates for forest biomass for landowners concerned with the NMB of the forest stock, when g_x is negative. But the effect will be ambiguous when g_x is positive for all landowners. The effect of the changes in marginal non-market thinning benefit is the same as that of the subsidy rate for thinnings.

These findings provide some interesting policy implications. First, government subsidies for forest biomass will affect landowners with varying attitudes on non-market goods and services differently. Second, the magnitude of the effects differs for equal changes in the logging residue and thinning subsidies. Third, different silvicultural practices, which change g_E, also influence the optimal steady state forest stock, harvest, and the intensity of silvicultural effort. Consequently, the effects of financial incentives are generally unclear. Lastly, marginal NMB of thinnings or logging residues have the same effect as government subsidies.

Therefore, increasing landowner awareness of the NMB of forest biomass can serve as a substitute of financial incentives for landowners who are concerned with the NMB of the forest stock.

Governmental subsidies for forest biomass will increase the long-run silvicultural effort of landowners who are not concerned with the NMB of the forest stock. The other effects on forest stock level, harvest, and silvicultural practices are ambiguous or depend on specific situations. Therefore, how government incentives will affect the sustainability of natural resources can be diverse.

This study assumes that net values of thinnings and logging residues are constant for the comparative static analysis of the effects of government subsidy rate changes. When harvesting costs of logging residues or thinnings are decreasing, probably due to technology improvement, the effects can be in the same direction as those of increasing government subsidy rate or market benefits. The magnitude of the effects, however, will be larger.

Though forest management is stochastic in nature (Gan et al. 2001), this study uses a deterministic model to explore the potential impacts of governmental policies on the long-run equilibrium forest stock, harvest and silvicultural effort. Also, this study assumes that the steady state solved from the necessary conditions is stable. Given a certain nonlinear forest growth function, any steady state can be non-unique. The stability of all steady states must be formally examined to see whether it is stable or a saddle point (Kaminen and Schwartz 1991; Amacher, Ollikainen, and Koskela 2009).

The study provides useful information on how bioenergy policies and the development of bioenergy production will affect the forest management, which is closely related to natural resource sustainability. It will be valuable not only for the new bioenergy industry and traditional wood processing industry, but also for policy makers. Nonetheless, these results may not be applied when forests are not in the steady state or affected by unusual situations such as catastrophic events.

APPENDIX

Table 5.1 Determination of the effect of increases in the subsidy rate for logging residues and thinnings on the optimal steady state stock, harvest, and silvicultural effort.

	Landowners with NMB for x		Firms without NMB for x	
	E, x complement	E, x substitute	E, x complement	E, x substitute
$\frac{\partial x^*}{\partial S_L}$	?	-	+	-
$\frac{\partial h^*}{\partial S_L}$	?	When $g_x<0$, +	When $g_x>0$, +	?
$\frac{\partial E^*}{\partial S_L}$	?	+	+	+
$\frac{\partial x^*}{\partial S_B}$	?	-	+	-
$\frac{\partial h^*}{\partial S_B}$	?	When $g_x<0$, +	When $g_x>0$, +	?
$\frac{\partial E^*}{\partial S_B}$	?	+	+	+
$\frac{\partial x^*}{\partial \rho_B}$	?	-		
$\frac{\partial h^*}{\partial \rho_B}$	?	When $g_x<0$, +		
$\frac{\partial E^*}{\partial \rho_B}$	?	+		

Table 5A.1. The first-order optimality conditions for social planners' and landowners' dynamic optimization problems.

Social Planners		*Landowners with NMB of x*		*Firms without NMB of x*	
$\dot{\mu} - \delta\mu = -U_x - \mu g_x$	*(1)*	$\dot{\mu} - \delta\mu = -U_x - \mu g_x$	*(7)*	$\dot{\mu} - \delta\mu = -\mu g_x$	*(13)*
$w = \mu g_E$	*(2)*	$w = \mu g_E$	*(8)*	$w = \mu g_E$	*(14)*
$V_{L^r} = U_{L^o}$	*(3)*	$V_{L^r} + S^{L^r} = U_{L^o}$	*(9)*	$V_{L^r} + S^{L^r} = U_{L^o}$	*(15)*
$V_B + U_B = \mu$	*(4)*	$V_B + S^B + U_B = \mu$	*(10)*	$V_B + S^B + U_B = \mu$	*(16)*
$V_h + V_{L^r} L_h = \mu$	*(5)*	$V_h + (V_{L^r} + S^{L^r}) L_h = \mu$	*(11)*	$V_h + (V_{L^r} + S^{L^r}) L_h = \mu$	*(17)*
$V_B + U_B = V_h + V_{L^r} L_h$	*(6)*	$V_B + S^B + U_B = V_h + (V_{L^r} + S^{L^r}) L_h$	*(12)*	$V_B + S^B + U_B = V_h + (V_{L^r} + S^{L^r}) L_h$	*(18)*

Eqs. (2), (8), and (14) state that the optimal silvicultural effort equates its marginal cost or price to the current value of its marginal product. This condition is the same as with no biomass benefits in the model. The following optimality conditions, however, are different from the results of previous study considering no biomass benefits (Gan et al. 2001). These conditions show how biomass benefits can affect the optimal rotation and the steady state forest stock and harvest.

Eq. (3) suggests that, for social planners, the optimal recovery of logging residues should equate the marginal market value of logging residues recovered to the marginal NMB of unrecovered logging residues plus the current value shadow price of the marginal growth response to logging residues. For all landowners, the optimal recovery of logging residues should equate the sum of the marginal market value and subsidy rate of logging residues recovered to the marginal NMB of unrecovered logging residues (Eqs. 9 and 15).

Eqs. (5), (11), and (17) indicate that the current value shadow price of the forest stock is different for social planners and landowners. For social planners, it equals the sum of the marginal timber benefit and the product of the marginal logging residue benefit and the marginal logging residue produced from harvest (Eq. 5). For landowners and firms, the product of the marginal logging residue produced from harvest and the marginal monetary value of logging residues (i.e., the sum of marginal market benefit and subsidy rate), together with marginal timber benefit, determines the optimal harvest level (Eqs. 11 and 17). .

Eq. (4) suggests that, for social planners at the optimal level, the sum of the marginal market and NMB of thinning must equal the current value shadow price of the forest stock. For all landowners and firms, the sum of the marginal market and NMB of thinning and subsidy rate equal the current value shadow price of the forest stock (Eqs. 10 and 16).

Eq. (6) indicates that, for social planners, the sum of the marginal timber and logging residue benefits equals the sum of marginal market and non-market thinning benefits. For landowners and firms, the subsidy rates for thinnings and logging residues add to the marginal market thinning benefit on the left-hand side and the marginal logging residue benefits on the right-hand side, respectively (Eqs. 12 and 18).

Table 5A.2. The effect of changes in subsidy rate for logging residues and thinnings on the optimal steady state stock, harvest, and silvicultural effort.

	Landowners concerning NMB of x	Firms not concerning NMB of x
$\frac{\partial x^*}{\partial S_L}$	$-\frac{L_h}{\lvert A\rvert}\cdot[g_E g_{xE}+\frac{\rho g_{EE}}{(P+(P_L+S^{L^r})L_h)}]$	$-\frac{L_h g_E g_{xE}}{\lvert A\rvert}$
$\frac{\partial h^*}{\partial S_L}$	$\frac{L_h}{\lvert A\rvert}\cdot[{g_E}^2 g_{xx}-g_x g_E g_{xE}-\frac{\rho(g_x g_{EE}-g_E g_{Ex})}{P+(P_L+S^{L^r})L_h}]$	$\frac{L_h}{\lvert A\rvert}\cdot[{g_E}^2 g_{xx}-g_x g_E g_{xE}]$
$\frac{\partial E^*}{\partial S_L}$	$\frac{L_h}{\lvert A\rvert}\cdot[g_E g_{xx}+\frac{\rho g_{Ex}}{P+(P_L+S^{L^r})L_h}]$	$\frac{L_h g_E g_{xx}}{\lvert A\rvert}$
$\frac{\partial x^*}{\partial S_B}$	$-\frac{1}{\lvert A\rvert}\cdot[g_E g_{xE}+\frac{\rho g_{EE}}{(P_B+S^B+\rho_B)}]$	$-\frac{g_E g_{xE}}{\lvert A\rvert}$
$\frac{\partial h^*}{\partial S_B}$	$\frac{1}{\lvert A\rvert}\cdot[{g_E}^2 g_{xx}-g_x g_E g_{xE}-\frac{\rho(g_x g_{EE}-g_E g_{Ex})}{(P_B+S^B+\rho_B)}]$	$\frac{{g_E}^2 g_{xx}-g_x g_E g_{xE}}{\lvert A\rvert}$
$\frac{\partial E^*}{\partial S_B}$	$\frac{1}{\lvert A\rvert}\cdot[g_E g_{xx}+\frac{\rho g_{Ex}}{(P_B+S^B+\rho_B)}]$	$\frac{g_E g_{xx}}{\lvert A\rvert}$
$\frac{\partial x^*}{\partial \rho_B}$	$-\frac{1}{\lvert A\rvert}\cdot[g_E g_{xE}+\frac{\rho g_{EE}}{(P_B+S^B+\rho_B)}]$	
$\frac{\partial h^*}{\partial \rho_B}$	$\frac{1}{\lvert A\rvert}\cdot[{g_E}^2 g_{xx}-g_x g_E g_{xE}-\frac{\rho(g_x g_{EE}-g_E g_{Ex})}{(P_B+S^B+\rho_B)}]$	
$\frac{\partial E^*}{\partial \rho_B}$	$\frac{1}{\lvert A\rvert}\cdot[g_E g_{xx}+\frac{\rho g_{Ex}}{(P_B+S^B+\rho_B)}]$	

Chapter 6

Summary and Conclusions

As an alternative renewable source for bioenergy, forest biomass has recently drawn more attention from the U.S. government and the general public. Many federal and state woody biomass policies encouraged the establishment of a new bioenergy industry. A variety of state policy incentives attempt to create a desirable economic and legal climate for new firms. New bioenergy plants also cautiously screen states for the most feasible locations. This context imposes two important questions regarding state government policies and the sustainable use of forest resources. This dissertation is composed of four essays, which shed some light on these questions.

Two essays examined the strength of state governmental incentives on woody biomass utilization and the significance of their impact on establishing new bioenergy plants. Essay one analyzed different categories of state regulations and programs. An index approach was employed to compare states in terms of the strength of incentives. The policy index was created based on the point of view of bioenergy investors. It not only provides valuable information for project directors to make siting decisions, but also helps state policy makers to enact new woody biomass legislation.

The second essay applied an econometric model to explore the effects of state attributes on new firms' location decisions in the southern U.S. The CLM results reveal a significant positive relationship between woody biomass policies and the location of new plants. Other state characteristics that influenced location choices of the bioenergy industry include forest resource endowment, tax structure, and labor force.

The final two essays highlight the issue of sustainable use of forest biomass. Based on the roundwood markets and forest resources in Tennessee, the third essay utilized the SRTS model to predict the impacts of additional demand for pulpwood for biorefinery production. The sesults indicate that overuse of pulpwood for biorefinery production will lead to rising softwood and hardwood pulpwood prices in Tennessee. Even the softwood sawtimber price will be affected due to the competition for timber between the new bioenergy industry and traditional wood processing industries.

These findings are also a warning of possible overuse of forest biomass. The development of a new bioenergy industry should be based on the availability of biomass and regional roundwood markets. The forest inventory and annual removals are the primary condition to determine the total capacity of biorefinery plants in an individual state. Moreover, forest type should be considered in terms of pulpwood supply. In Tennessee, the forests are dominated by hardwoods, and therefore using more hardwood for biofuel production is feasible. In other states with large areas of pine plantations, different scenarios of forest biomass usage should be applied. In the case of intense regional roundwood market competition, biorefinery production using pulpwood may not be practical. However, other bioenergy plants using small diameter wood can be built to make good use of the natural resources and promote economic growth.

The fourth essay included the benefits of thinning and logging residues in a dynamic optimization model to explore how woody biomass policies will affect forest stock, harvest levels, optimal rotation, and silvicultural effort. Results revealed that incentives for using thinning materials and logging residues will have similar effects on the optimal steady state forest stock, harvest, and silvicultural efforts in the long-run. However, the magnitude of the effects differs. Governmental subsidies for forest biomass will increase the long-run silvicultural effort of landowners who are not concerned with the NMB of the forest stock. The other effects on forest stock level, harvest, and silvicultural practices are ambiguous or depend on specific situations. Therefore, how government incentives will affect the sustainability of natural resources can be diverse. These findings will offer constructive insights in the enactment and implementation of new woody biomass legislation.

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