Projecting Landscape Forest Carbon Emissions from Changes in Forest Biomass Electricity Generation and Forest Products Markets from 2014 to 2035:

An Analysis in Minnesota, Oregon, South Carolina, Virginia, and Washington

February 2018

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Table of Contents

1. Introduction and Executive Summary 1
2. United States 2
    - 2.1. Executive Summary 2
    - 2.2. Introduction 2
    - 2.3. Energy Profile 2
        - 2.3.1. Energy Production and Consumption 2
        - 2.3.2. Electricity Production and Consumption 2
        - 2.3.3. Electricity from Forest Biomass Resources 3
        - 2.3.4. Biomass Thermal Heat Generation 4
        - 2.3.5. US Energy Choices 5
        - 2.3.6. Biomass Energy CO_2 and Other Emissions 5
    - 2.4. Forest Sector Profile 7
        - 2.4.1. The Condition of the Forest Resource 7
        - 2.4.2. The Forest Industry 9
    - 2.5. Conclusion 9
    - 2.6. References 9
    - 2.7. Appendix A 12
3. Minnesota 13
    - 3.1. Executive Summary 13
    - 3.2. Introduction 16
    - 3.3. Minnesota Energy Profile 16
        - 3.3.1. Energy Production and Consumption 16
        - 3.3.2. Electricity Production and Consumption 17
        - 3.3.3. Electricity from Forest Biomass Resources 18
        - 3.3.4. Biomass Thermal Heat Generation 18
        - 3.3.5. State Energy Choices 19
        - 3.3.6. Biomass Energy CO_2 and Other Emissions 19
    - 3.4. Forest Sector Profile 21
        - 3.4.1. The Condition of the Forest Resource 21
        - 3.4.2. The Forest Industry 23
    - 3.5. Forest CO_2 Modeling 24
        - 3.5.1. Model Parameters and Inputs 24
        - 3.5.2. Minnesota Model Scenarios 26
        - 3.5.3. Minnesota Model Scenarios Results 27
    - 3.6. Conclusion 30
    - 3.7. References 30
    - 3.8. Appendix A 33
4. Oregon 34
    - 4.1. Executive Summary 34
    - 4.2. Introduction 37
    - 4.3 Oregon Energy Profile 37
        - 4.3.1. Energy Production and Consumption 37
        - 4.3.2. Electricity Production and Consumption 38

        - 4.3.3. Electricity from Forest Biomass Resources 39
        - 4.3.4. Biomass Thermal Heat Generation 39
        - 4.3.5. State Energy Choices 40
        - 4.3.6. Biomass Energy CO_2 and Other Emissions 40
    - 4.4. Forest Sector Profile 42
        - 4.4.1. The Condition of the Forest Resource 42
        - 4.4.2. The Forest Industry 44
    - 4.5. Forest CO_2 Modeling 44
        - 4.5.1. Model Parameters and Inputs 44
        - 4.5.2. Oregon Model Scenarios 47
        - 4.5.3. Oregon Model Scenarios Results 48
    - 4.6. Conclusion 50
    - 4.7. References 51
    - 4.8. Appendix A 54
- 5. South Carolina 55
    - 5.1 Executive Summary 55
    - 5.2. Introduction 58
    - 5.3 South Carolina Energy Profile 58
        - 5.3.1. Energy Production and Consumption 58
        - 5.3.2. Electricity Production and Consumption 59
        - 5.3.3. Electricity from Forest Biomass Resources 60
        - 5.3.4. Biomass Thermal Heat Generation 60
        - 5.3.5. State Energy Choices 61
        - 5.3.6. Biomass Energy CO_2 and Other Emissions 61
    - 5.4. Forest Sector Profile 63
        - 5.4.1. The Condition of the Forest Resource 63
        - 5.4.2. The Forest Industry 65
    - 5.5. Forest CO_2 Modeling 65
        - 5.5.1. Model Parameters and Inputs 65
        - 5.5.2. South Carolina Model Scenarios 67
        - 5.5.3. South Carolina Model Scenario Results 69
    - 5.6. Conclusion 72
    - 5.7. References 73
    - 5.8. Appendix A 76
- 6. Virginia 77
    - 6.1 Executive Summary 77
    - 6.2. Introduction 80
    - 6.3. Virginia Energy Profile 80
        - 6.3.1. Energy Production and Consumption 80
        - 6.3.2. Electricity Production and Consumption 81
        - 6.3.3. Electricity from Forest Biomass Resources 82
        - 6.3.4. Biomass Thermal Heat Generation 82
        - 6.3.5. State Energy Choices 83
        - 6.3.6. Biomass Energy CO_2 and Other Emissions 83

6.4. Forest Sector Profile ... 85
    6.4.1. The Condition of the Forest Resource ... 85
    6.4.2. The Forest Industry ... 87
6.5. Forest CO_2 Modeling ... 87
    6.5.1. Model Parameters and Inputs ... 87
    6.5.2. Virginia Model Scenarios ... 89
    6.5.3. Virginia Model Scenarios Results ... 90
6.6. Conclusion ... 93
6.7. References ... 94
6.8. Appendix A ... 97
7. Washington ... 98
7.1 Executive Summary ... 98
7.2. Introduction ... 101
7.3. Washington Energy Profile ... 101
    7.3.1. Energy Production and Consumption ... 101
    7.3.2. Electricity Production and Consumption ... 102
    7.3.3. Electricity from Forest Biomass Resources ... 103
    7.3.4. Biomass Thermal Heat Generation ... 103
    7.3.5. State Energy Choices ... 104
    7.3.6. Biomass Energy CO_2 and Other Emissions ... 104
7.4. Forest Sector Profile ... 106
    7.4.1. The Condition of the Forest Resource ... 106
7.4.2. The Forest Industry ... 108
7.5. Forest CO_2 Modeling ... 108
    7.5.1. Model Parameters and Inputs ... 108
    7.5.2. Washington Model Scenarios ... 111
    7.5.3. Washington Model Scenarios Results ... 112
7.6. Conclusion ... 114
7.7. References ... 115
7.8. Appendix A ... 118

List of Tables

Table 2.1. Million Megawatt hours of Electricity for United States, by Energy Source 3
Table 2.2. United States Net Generation from “Wood and Wood Derived Fuels” by Type of Producer and Year in million megawatt hours 4
Table 2.3. US Energy Consumption Estimates for Thermal and Electricity Power from “Wood, Wood-Derived Fuel, and Biomass Waste” by Year and Type of Producer in trillion Btu 4
Table 2.4. United States Estimated Emission from “Wood and Wood-Derived Fuel” by Type of Producer in metric tons 6
Table 2.5. United States Land Area, by Year, in millions of acres 7
Table 2.6. United States Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 8
Table 2.7. United States Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in million cubic feet 8
Table 2.8. United States Timberland Area by Ownership, 2017, in thousands of acres 8
Table 2.9. United States Volume of Industrial Timber Products by Ownership Class and Timber Product, 2011, in millions of cubic feet 9
Table 3.1. Electricity Generation and Emissions for Minnesota, by Energy Source 17
Table 3.2. Minnesota Net Generation from “Wood and Wood Derived Fuels” by Type of Producer and Year in thousand megawatt hours 18
Table 3.3. Minnesota Energy Consumption Estimates for Thermal and Electricity Power from “Wood, Wood-Derived Fuel, and Biomass Waste” by Year and Type of Producer in trillion Btu 18
Table 3.4. Minnesota Estimated Emission from “Wood and Wood-Derived Fuel” by Type of Producer in metric tons 20
Table 3.5. Minnesota Land Area, by Year, in thousands of acres 21
Table 3.6. Minnesota Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 22
Table 3.7. Minnesota Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in thousand cubic feet 22
Table 3.8. Minnesota Timberland Area by Ownership, 2017, in thousands of acres 23
Table 3.9. Minnesota Volume of Industrial Timber Products by Ownership Class and Timber Product, 2011, in millions of cubic feet 23
Table 3.10. Total number of wood using facilities, production capacity, and foreign trade for wood products in Minnesota, 2014 25
Table 3.11. Minnesota modeled scenarios of location, size, and feedstock 27
Table 4.1. Electricity Generation and Emissions for Oregon, by Energy Source 38
Table 4.2. Oregon Net Generation from “Wood and Wood Derived Fuels” by Type of Producer and Year in thousand megawatt hours 39
Table 4.3. Oregon Energy Consumption Estimates for Thermal and Electricity Power from “Wood, Wood-Derived Fuel, and Biomass Waste” by Year and Type of Producer in trillion Btu 40

Table 4.4. Oregon Estimated Emission from “Wood and Wood-Derived Fuel” by Type of Producer in metric tons 41
Table 4.5. Oregon Land Area, by Year, in thousands of acres 42
Table 4.6. Oregon Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 43
Table 4.7. Oregon Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in thousand cubic feet 43
Table 4.8. Oregon Timberland Area by Ownership, 2017, in thousands of acres (Source: Oswalt et al 2018 44
Table 4.9. Oregon Volume of Industrial Timber Products by Ownership Class and Timber Product, 2011, in millions of cubic feet 44
Table 4.10. Total number of wood using facilities, production capacity, and foreign trade for wood products in Oregon, 2014 46
Table 4.11. Oregon modeled scenarios of potential facility location, size, and feedstock 48
Table 4.12. Average annual net change in landscape live tree carbon emissions, 2019-2035 50
Table 5.1. Electricity Generation and Emissions for South Carolina, by Energy Source 59
Table 5.2. South Carolina Net Generation from “Wood and Wood Derived Fuels” by Type of Producer and Year in thousand megawatt hours 60
Table 5.3. South Carolina Energy Consumption Estimates for Thermal and Electricity Power from “Wood, Wood-Derived Fuel, and Biomass Waste” by Year and Type of Producer in trillion Btu 61
Table 5.4. South Carolina Estimated Emission from “Wood and Wood-Derived Fuel” by Type of Producer in metric tons 62
Table 5.5. South Carolina Land Area, by Year, in thousands of acres 63
Table 5.6. South Carolina Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 64
Table 5.7. South Carolina Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in thousand cubic feet 64
Table 5.8. South Carolina Timberland Area by Ownership, 2017, in thousands of acres (Source: Oswalt et al 2018 65
Table 5.9. South Carolina Volume of Industrial Timber Products by Ownership Class and Timber Product, 2014, in millions of cubic feet 65
Table 5.10. Estimate of additional demand (U.S. green tons) by product class 66
Table 5.11. Total number of wood using facilities, production capacity, and demand for wood products in South Carolina, 2014 67
Table 5.12. South Carolina modeled scenarios 68
Table 5.13. Average annual net change in landscape forest carbon emissions, 2019-2035 72
Table 6.1. Electricity Generation and Emissions for Virginia, by Energy Source 81
Table 6.2. Virginia Net Generation from “Wood and Wood Derived Fuels” by Type of Producer and Year in thousand megawatt hours 82

Table 6.3. Virginia's Energy Consumption Estimates for Thermal and Electricity Power from "Wood, Wood-Derived Fuel, and Biomass Waste" by Year and Type of Producer in trillion Btu 83
Table 6.4. Virginia Estimated Emission from "Wood and Wood-Derived Fuel" by Type of Producer in metric tons 84
Table 6.5. Virginia Land Area, by Year, in thousands of acres 85
Table 6.6. Virginia Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 86
Table 6.7. Virginia Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in thousand cubic feet 86
Table 6.8. Virginia Timberland Area by Ownership, 2017, in thousands of acres (Source: Oswalt et al 2018 87
Table 6.9. Virginia Volume of Industrial Timber Products by Ownership Class and Timber Product, 2011, in millions of cubic feet 87
Table 6.10. Total number of wood using facilities, production capacity, and foreign trade for wood products in Virginia, 2014 88
Table 6.11. Virginia modeled scenarios 90
Table 6.12. Average annual net change in landscape forest carbon emissions, 2023-2035 93
Table 7.1. Electricity Generation and Emissions for Washington, by Energy Source 102
Table 7.2. Washington Net Generation from "Wood and Wood Derived Fuels" by Type of Producer and Year in thousand megawatt hours 103
Table 7.3. Washington Energy Consumption Estimates for Thermal and Electricity Power from "Wood, Wood-Derived Fuel, and Biomass Waste" by Year and Type of Producer in trillion Btu 104
Table 7.4. Washington Estimated Emission from "Wood and Wood-Derived Fuel" by Type of Producer in metric tons 105
Table 7.5. Washington Land Area, by Year, in thousands of acres 106
Table 7.6. Washington Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 107
Table 7.7. Washington Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in thousand cubic feet 107
Table 7.8. Washington Timberland Area by Ownership, 2017, in thousands of acres (Source: Oswalt et al 2018 108
Table 7.9. Washington Volume of Industrial Timber Products by Ownership Class and Timber Product, 2011, in millions of cubic feet 108
Table 7.10. Total number of wood using facilities, production capacity, and foreign trade for wood products in Washington, 2014 110
Table 7.11. Washington modeled scenarios of potential facility location, size, and feedstock 112
Table 7.12. Average annual net change in landscape live tree carbon emissions, 2019-2035 114

List of Figures

Figure 3.1. Minnesota Energy Consumption Estimates, 2015 16
Figure 3.2. Minnesota Primary Wood-Using Mills and Bioenergy Expansion Scenario Locations, 2014 24
Figure 3.3. Projected change in national forest products industry production, 2014-2034 25
Figure 3.4. Cumulative carbon stock change from baseline for Minnesota scenarios, 2018 – 2035 28
Figure 4.1. Oregon Energy Consumption Estimates, 2015 37
Figure 4.2. Oregon Primary Wood-Using Mills and Bioenergy Expansion Scenario Locations, 2014 45
Figure 4.3. Projected change in national forest products industry production, 2014-2034 47
Figure 4.4. Cumulative carbon stock change from baseline for Oregon scenarios, 2018 – 2035 49
Figure 5.1. South Carolina Energy Consumption Estimates, 2015 58
Figure 5.2. South Carolina Primary Wood-Using Mills, by Region, 2014 66
Figure 5.3. Price, inventory, and removal indices for multiple forest products, assuming the addition of one (1) 20MW facility with 50% residue recovery 70
Figure 5.4. Price, inventory, and removal indices for multiple forest products, assuming the addition of eight (8) 20MW facilities with 0% residue recovery 70
Figure 5.5. Cumulative carbon stock change from baseline for South Carolina scenarios, 2018 – 2035. The figure on the left represents zero residue utilization, the figure on the right 50% 71
Figure 6.1. Virginia Energy Consumption Estimates, 2015 80
Figure 6.2. Virginia Primary Wood-Using Mills, by Region, 2014 89
Figure 6.3. Price, inventory, and removal indices for multiple forest products, assuming loss of one (1) 51 MW bioenergy facility in 2023 91
Figure 6.4. Price, inventory, and removal indices for multiple forest products, assuming the loss of four (4) 51 MW existing facilities in 2023 91
Figure 6.5. Aggregate land use change in Virginia by scenario 92
Figure 6.6. Cumulative carbon stock change from baseline for Virginia scenarios, 2018 – 2035 92
Figure 7.1. Washington Energy Consumption Estimates, 2015 101
Figure 7.2. Washington Primary Wood-Using Mills and Bioenergy Expansion Scenario Locations, 2014 109
Figure 7.3. Projected change in national forest products industry production, 2014-2034 111
Figure 7.4. Cumulative carbon stock change from baseline for Washington scenarios, 2018 – 2035 113

1. Introduction and Executive Summary

Introduction

Organization of the Report

This report consists of seven chapters. Chapter 2 provides the national context for the state chapters that follow. The five state chapters are designed so that they can be extracted from the report and function as standalone documents for audiences interested in a particular state. For this purpose, background and appendix information is repeated in each chapter.

All the chapters follow a template that, after an Executive Summary and Introduction, provide an overview of the corresponding state's energy and forest sectors using US Energy Information Agency (EIA) and USDA Forest Inventory and Analysis (FIA) data, respectively. The chapters then provide information on model parameters, inputs, and modeled scenarios before discussing scenario results.

Changes in forest products markets were modeled as a result of changes in forest biomass electricity generation, which results in a change in landscape forest carbon emissions. Forest products markets and carbon emissions were projected using one of two models, depending on the state. Minnesota, Oregon, and Washington scenarios were developed in consultation with state forest and regulatory agencies and analyses performed using the Land Use and Resource Allocation (LURA) model. South Carolina and Virginian scenarios were developed in a similar manner, and analyses were performed using the SubRegional Timber Supply (SRTS) model.

Scenario Comparisons

While the LURA and SRTS models have similarities, many model assumptions and subsequent analyses differ. Comparison of scenarios within states are valid and represent this report's most important findings. But model differences and variation in state scenarios prevent valid cross-state comparisons and should be avoided. Also, model results are based almost exclusively on electricity generation; results do not analyze the forest product markets, carbon emission, and land use change impacts of using forest biomass in combined heat and power (CHP) facilities or thermal facilities.

2. United States

2.1 Executive Summary

Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to provide context for state analyses. While the energy and forest profiles of the five states examined in this report differ from the US as a whole, the states are somewhat representative of their US region. Thus, the modeling results provided in the following chapters provide important lessons and insights that may be indicative of the impact of new bioenergy production on carbon emissions on neighboring states.

2.2. Introduction

The impact of new bioenergy production on landscape carbon emissions in the US is a function of existing energy production and consumption, forest growth and respiration, change in land use, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to provide context for state analyses.

2.3 Energy Profile

2.3.1. Energy Production and Consumption

The United States' energy profile is comprised of energy production, energy consumption, and energy imports, which are a function of price and availability.[1] In 2015, the most recent year comprehensive US Energy Information Agency (EIA) data are available,[2] the US's primary energy production included natural gas (32,810.1 trillion British Thermal Units (Btu)), crude oil (19,646.6 trillion Btu), coal (17,931 trillion Btu), nuclear electricity power (8,336.9 trillion Btu) and renewable energy (9,324 trillion Btu) (EIA 2017a, Table P2).

2.3.2. Electricity Production and Consumption

The US produced 4,077.6 million Megawatt hours (MWh) of electricity in 2015 (EIA 2016a), which was slightly more than produced in 2006 (Table 2.1). The majority of that electricity was produced from fossil fuels, namely, coal (33.2%), natural gas (32.7%), and petroleum (0.7%), with nuclear power (19.6%), providing most of the remaining production (EIA 2016a). More than 12 percent of the US's electricity was generated from renewable energy sources, with hydropower providing 6.1 percent, wind 4.7 percent, wood and wood derived fuels 1 percent, and solar thermal and photovoltaic 0.6 percent (EIA 2016a).

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[1] Since energy prices are fairly volatile, this report does not include price information. Historic (1970-2015) energy price information is available at: https://www.eia.gov/state/seds/sep_prices/notes/pr_print.pdf.

[2] As of October 2017.

Table 2.1. Million Megawatt hours of Electricity for United States, by Energy Source (Source: EIA 2016a).

Year	Coal	Natural Gas	Petroleum	Nuclear	Hydroelectric Conventional	Wood and Wood Derived Fuels	Solar Thermal & Photovoltaic	Wind	Other*	Total**
2006	1,990.5	816.4	64.2	787.2	289.2	38.8	0.5	26.6	51.3	**4,064.7**
2007	2,016.5	896.6	65.7	806.4	247.5	39	0.6	34.4	49.9	**4,156.7**
2008	1,985.8	883	46.2	806.2	254.8	37.3	0.9	55.4	49.8	**4,119.4**
2009	1,755.9	921	38.9	798.9	273.4	36.1	0.9	73.9	51.4	**3,950.3**
2010	1,847.3	987.7	37.1	807	260.2	37.2	1.2	94.7	52.8	**4,125.1**
2011	1,733.4	1.013.7	30.2	790.2	319.4	37.4	1.8	120.2	53.8	**4,100.1**
2012	1,514	1,225.9	23.2	769.3	276.2	37.8	4.3	140.8	56.1	**4,047.8**
2013	1,581.1	1,124.8	27.2	789	268.6	40	9.0	167.8	58.4	**4,066**
2014	1,581.7	1,126.6	30.2	797.2	259.4	42.3	17.7	181.7	56.3	**4,093.6**
2015	1,352.4	1,333.5	28.3	797.2	249.1	41.9	24.9	190.7	59.7	**4,077.6**

* "Other" includes EIA categories "Other Biomass" (produced an average of 19.1 million MWh per year), "Geothermal (average: 15.3 million MWh per year)", "Other" (average: 13.1 million MWh per year), "Other Gases" (average: 11.1 million MWh per year), and "Pumped Storage" (average: -5.7 million MWh per year -- pumped storage is negative because "more electricity is used to force the water uphill … than is produced when it flows downhill during the day" (EIA 2013)).

** Row totals may not add up due to rounding and sources omitted in accordance with previous note.

The US's electricity generators and combined heat and power (CHP) generators produced 4077.7 million MWh of electricity in 2015. Electricity generators produced the vast majority of this (3,764.1 million MWh; 92.3% of all generation), of which electricity utilities generated 2,315.5 million MWh and independent power producers generated 1,448.8 million MWh (EIA 2016a). CHP facilities generated only 313.5 million MWh of the US's electricity – electricity power CHPs generated 155.2 million MWh, and industrial power CHPs and commercial power CHPs generated 145.7 million MWh and 12.6 million MWh, respectively (EIA 2016a).

The US consumed 3,759 million MWh of electricity and exported 318.6 million MWh in 2015 (EIA 2016a; EIA 2016b). The largest shares of electricity used within the nation was by the residential (37.4%) and commercial (36.2%) sectors. The industrial sector consumed 26.2 percent and the transportation sector consumed 0.2 percent of this electricity (EIA 2016b).

2.3.3. Electricity from Forest Biomass Resources

In 2015, net electricity generation from forest biomass, using EIA's Wood and Wood Derived Fuel definition,[3] provided 41.9 million MWh (1%) of the nation's electricity (Table 2.2) – and more than any other sources besides coal, natural gas, nuclear, conventional hydroelectric, and wind (Table 2.1) (EIA 2016a). Forest biomass-based electricity generation increased 8 percent from 2006 to 2015, with 65.2 percent of that electricity in 2015 produced by industrial power CHP facilities (EIA 2016a).

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[3] EIA (2017c) defines Wood and Wood-Derived Fuels as "Wood/Wood Waste Solids (including paper pellets, railroad ties, utility poles, wood chips, bark, and wood waste solids)[,] Wood Waste Liquids (excluding Black Liquor but including red liquor, sludge wood, spent sulfite liquor, and other wood-based liquids)[, and] Black Liquor. *Note:* EIA's (2017c) "Other Biomass" category includes other types of biomass, such as "Agricultural By-Products[,] Municipal Solid Waste[,] Other Biomass Gas (including digester gas, methane, and other biomass gases) [,] Other Biomass Liquids[,] Other Biomass Solids[,] Landfill Gas[, and] Sludge Waste. However, since this report's modeling focuses on forest biomass and its derivatives, this report focuses exclusively on EIA's Wood and Wood-Derived Fuels.

Table 2.2. United States Net Generation from "Wood and Wood Derived Fuels" by Type of Producer and Year in million megawatt hours (Source: EIA 2016a).

Year	Combined Heat and Power			Electricity Generators		Total*
	Industrial Power	Commercial Power	Electricity Power	Independent Power Producers	Electricity Utilities	
2006	28.4	0	2	6.4	1.9	**38.8**
2007	28.3	0	2	6.5	2.2	**39**
2008	26.6	0	2	6.7	1.9	**37.3**
2019	25.3	0	2.3	6.7	1.7	**36.1**
2010	25.7	0	2.1	7	2.1	**37.2**
2011	26.7	0	2	6.9	2	**37.4**
2012	26.7	0	2.3	6.9	1.8	**37.8**
2013	27.7	0	2.2	7.6	2.5	**40**
2014	27.2	0.1	2.4	9.6	3	**42.3**
2015	27.3	0	2.2	9.3	3	**41.9**

* Row totals may not add up due to rounding and sources omitted in accordance with previous note.

2.3.4. Biomass Thermal Heat Generation

In 2015, heat from wood, wood-derived fuels, and biomass waste[4] was used in the US's residential, commercial, and industrial sectors (Table 2.3) (EIA 2017b). EIA estimated that thermal uses (2,064 trillion Btu) of these materials in the US were nearly four times as much as the 525 trillion Btu from the use of biomass to produce electricity (EIA 2017b, Tables CT3 and CT8),[5] and that the nation's thermal use of forest biomass decreased 1.1 percent from 2006 to 2015.

Table 2.3. US Energy Consumption Estimates for Thermal and Electricity Power from "Wood, Wood-Derived Fuel, and Biomass Waste" by Year and Type of Producer in trillion Btu (Source: EIA 2017b, Tables CT2, CT3, CT4, CT5, CT6, CT8).

Year	Thermal Power (trillion Btu)				Electricity Power (trillion Btu)	Total Consumption (trillion Btu)
	Residential Sector (million cords*)	Commercial Sector	Industrial Sector	Thermal Total		
2006	380 (19)	101	1,606	2,088	408	**2,496**
2007	420 (21)	101	1,562	2,083	419	**2,502**
2008	470 (24)	107	1,486	2,063	431	**2,494**
2009	504 (25)	109	1,336	1,949	438	**2,387**
2010	440 (22)	108	1,442	1,989	459	**2,449**
2011	450 (23)	112	1,474	2,035	437	**2,472**
2012	420 (21)	106	1,498	2,024	453	**2,477**
2013	580 (29)	117	1,499	2,196	470	**2,666**
2014	590 (30)	122	1,515	2,228	530	**2,758**
2015	440 (22)	128	1,496	2,064	525	**2,589**

* EIA only estimated cord wood usage for this sector (EIA 2017b, Table CT4).

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[4] EIA (2017c) defines biomass waste as "[o]rganic non-fossil material of biological origin that is a byproduct or a discarded product. Biomass waste includes municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural crop byproducts, straw, and other biomass solids, liquids, and gases; but excludes wood and wood-derived fuels (including black liquor), biofuels feedstock, biodiesel, and fuel ethanol. Note: EIA biomass waste data also include energy crops grown specifically for energy production, which would not normally constitute waste." *Note:* This definition differs from EIA's definition of "Other Biomass" – see previous footnote.

[5] "The electric power sector comprises electricity-only and combined-heat-and-power (CHP) plants ... whose primary business is to sell electricity, or electricity and heat, to the public" (EIA 2017b, 441).

2.3.5. US Energy Choices

The US's energy policy choices are based on local, state, regional, and national goals, such as economic development, energy security, energy reliability (e.g., base and peak load capacity), energy prices, and air pollution emissions, including greenhouse gas emissions. These policies influence the nation's energy mixes and can cause energy producers and consumers to favor one or more energy sources over others.

As Ebers et al. (2016, 67) noted as of "September 2013, federal and state governments had created 494 policies to support production of electricity and heat from forest biomass." Building on Becker et al. (2011), Ebers et al. (2016, 67) developed "a four-tier classification structure to categorize policy instruments based on: approach (incentive, regulation, information), type (e.g. tax incentive), subcategory (e.g. tax exemption), and specification (e.g. sales tax exemption)" (see Appendix A).

The most common US policy approaches focused on stimulating forest biomass energy were personal tax credits, research and development grants, and education and outreach.[6] Other incentives specific to renewable energy, but not limited to electricity or heat produced from forest biomass, included investment tax credits, production tax credits, depreciation allowances, grants, federal bonds green power purchasing, interconnection standards, and technical assistance (Ebers et al. 2016).

2.3.6. Biomass Energy CO_2 and Other Emissions

US energy choices regarding fossil fuels and renewables to produce heat and electricity have CO_2 and other emission implications. Emissions from biomass energy generation vary greatly depending on the feedstock source, location, conversion efficiency, and other factors. Combining heat with electricity production significantly increases efficiency over standalone electricity production and reduces GHG emissions per unit of energy generation, while dried forest biomass (e.g., pellets and dried wood chips) generally provides higher conversion efficiencies than green wood chips (Schlamadinger et al. 1997). Feedstock proximity, which affects greenhouse gas emissions from biomass transportation also impacts emissions, with biomass facilities price- and volume-constrained based on feedstock availability and competition from other biomass users (Schlamadinger et al. 1997, Galik et al. 2009).

In 2015, electricity production from *all sources* in the US produced an estimated 2,031 million metric tons of CO_2, 2.5 million metric tons of SO_2, and 1.8 million metric tons of NO_X (EIA 2016c). Of these emissions, wood and wood-derived fuels produced 8.6 percent of the nation's SO_2 emissions and 4.1 percent of its NO_X emissions (Table 2.4) (EIA 2016c). Because the EIA follows current international convention and assumes that CO_2 "released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions" (EIA 2011), *none* of the US's estimated CO_2 electricity emissions include CO_2 emissions from biomass.[7]

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[6] The policy approaches reported in this paragraph use Ebers et al.'s (2016) policy names/terminology.

[7] As EIA notes, "According to current international convention, CO_2 released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions. The related fossil fuel emissions from the transportation and processing of the biological feedstocks are captured within overall energy sector emissions, but currently they are not allocated to the biofuels. Additionally, the CO_2 released from biofuel or bioenergy combustion is assumed to be fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy. However, analysts have debated whether the increased use of biomass energy may result in a loss of terrestrial carbon stocks and foregone future sequestration by natural vegetation. The initial loss of carbon stocks in natural vegetation cleared to grow biomass feedstocks and the foregone future removal of CO_2 are not captured in energy sector emissions. To capture the potential net emissions, the international convention for GHG inventories is to report the net carbon flux from land use change (such as when forests are converted to cropland to grow feedstocks) in the Land Use category. Although accounting for land use emissions is more challenging than for most of the other emissions sources, emissions and sequestration associated with domestic U.S. land use change should in principle be accounted for in this chapter of the inventory report. However, from a global greenhouse gas emissions perspective, the key uncertainty regarding aggregate net biogenic emissions is indirect land use change that occurs abroad." (EIA 2011).

Table 2.4. United States Estimated Emission from “Wood and Wood-Derived Fuel” by Type of Producer in metric tons (Source: EIA 2016c).

Year	Emission	Electric Utility	Independent Power Producers		Commercial		Industrial		Total
			Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	
2006	SO_2	162	916	345	0	12	537	209,639	**211,611**
	NO_x	1,440	6,470	2,813	0	110	510	65,196	**76,539**
2007	SO_2	157	873	458	0	21	608	207,948	**210,065**
	NO_x	1,588	5,927	3,171	0	189	612	61,608	**73,095**
2008	SO_2	255	1,032	385	0	16	1,988	206,038	**209,714**
	NO_x	1,993	6,895	2,807	1	146	827	58,753	**71,422**
2009	SO_2	264	996	622	0	12	0	206,558	**208,452**
	NO_x	1,875	6,476	3,615	2	110	0	59,002	**71,080**
2010	SO_2	358	1,568	622	0	12	1	203,050	**205,611**
	NO_x	2,621	7,764	3,418	0	107	5	60,724	**74,639**
2011	SO_2	417	1,285	556	2	11	20	219,107	**221,398**
	NO_x	2,319	7,174	3,024	22	103	146	63,242	**76,030**
2012	SO_2	403	1,101	576	3	10	8,009	209,477	**219,576**
	NO_x	2,040	6,625	3,344	25	92	2,903	59,537	**74,566**
2103	SO_2	398	1,507	604	3	9	4,364	211,979	**218,864**
	NO_x	4,152	7,481	3,260	30	86	1,376	63,783	**80,168**
2014	SO_2	330	1,540	329	3	24	4,579	211,102	**217,907**
	NO_x	2,784	7,015	2,939	36	304	1,633	64,068	**78,779**
2015	SO_2	382	1,415	488	0	31	25	212,720	**215,061**
	NO_x	2,569	6,621	2,499	3	375	92	62,386	**74,545**

While international convention and the EIA assume that “the CO_2 released from biofuel or bioenergy combustion … [is] fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy,” (EIA 2011, 60) from a landscape perspective forests can be a CO_2 sink, CO_2 source, or carbon neutral (Malmsheimer et al. 2008). Forests are a CO_2 sink when live and dead vegetation, litter, and soil sequester more carbon than emitted, and forests are a carbon source when these emissions exceed sequestration rates (Wear and Coulston 2015). Management actions such as timber harvesting, or natural disturbances like wildfires affecting the CO_2 balance determines the extent to which a forest is a net sink or source of CO_2 to the atmosphere (Woodall et al. 2015). Carbon is also sequestered in harvested wood products, such as lumber and paper, which affects the CO_2 balance (EIA 2011; Malmsheimer et al. 2008). At the end of a products’ useful life, the carbon is either released directly into the atmosphere through burning and energy combustion (Malmsheimer et al. 2011; Miner et al. 2014), or natural decomposition or decay in landfills (Skog 2008).[8]

While most forest-based carbon is eventually released into the atmosphere, forest products and forest biomass energy provide documented benefits. As Malmsheimer et al. (2011, S9) described, “[f]orest products used in place of energy intensive materials such as metals, concrete and plastics (a) reduce carbon emissions (because forest products require less fossil fuel-based energy to produce), (b) store carbon (for a length of time based on products’ use and disposal), and (c) provide biomass residuals (i.e., waste wood) that can be substituted for fossil fuels to produce energy. [In addition,] [f]ossil fuel–produced energy releases carbon into the atmosphere that has resided in the Earth for millions of years; forest biomass–based energy uses far less of the carbon stored in the Earth thereby reducing the flow of fossil fuel–based carbon emissions to the atmosphere.”

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[8] As Malmsheimer et al. (2011, S30), noted “Of the wood products that enter solid waste disposal sites, more than three quarters of the carbon in solid wood and almost one-half of the carbon in paper is never released to the atmosphere … . The carbon that is released during decay takes many years to reach the atmosphere. For example, the 23% of the solid wood that does decay has a half-life of 29 years. Skog (2008) found that when paper is landfilled, the nonlignin component (56%) decays, leaving the lignin component (44%) as a long-term store in the landfill … . This nondegradable fraction varies by grade, from approximately 10% for bleached chemical pulp fibers to 85% for mechanical pulp fibers (US EPA 2006).”

2.4. Forest Sector Profile

2.4.1. The Condition of the Forest Resource

As a lower value commodity relative to sawlogs and other forest products, the availability of biomass for energy generation often depends on traditional forest products markets to generate sufficient financial incentive to enable biomass removal (Oswalt et al. 2018; Miner et al. 2014). These markets depend in large part on the condition of a state's forest resource, species composition, and forest products manufacturing base.

More than one-third (33.8%) of the US is forested, and the number of acres has decreased slightly since 2011 (Table 2.5) (Oswalt et al. 2014; 2018). Almost 87 percent of the nation's timberlands – forests producing or capable of producing industrial wood, and not withdrawn from timber utilization – have natural origins, as opposed to being planted (Oswalt et al. 2018).

Table 2.5. United States Land Area, by Year, in millions of acres (Sources: Oswalt et al. 2014; 2018 (Tables 1a)).

Year	Total Land Area	Forestland*					Woodland****	Other Land
		Total	Timberland**		Reserved***	Other		
			Planted	Natural Origin				
2011	2,261	766	65	456	73	172	53	1,442
2017	2,261	765	67	447	81	170	57	1,437

* Forestland is defined as, "Land at least 120 feet (37 meters) wide and at least 1 acre (0.4 hectares) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. The definition here includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest land also includes transition zones, such as areas between forest and nonforest lands that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (37 meters) wide or an acre in size. Forest land does not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

** Timberland is defined as, "Forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. (Note: Areas qualifying as timberland are capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.)" (U.S. Forest Service 2017a).

*** Woodland is defined as, "a class of land which consists predominantly of stands of sparse woodland species such as juniper, pinyon juniper, mesquite and small stature hardwood species and are found in the arid to semiarid regions of the interior western United States. These areas must span more than 1 acre (0.4 hectares, have sparse trees capable of achieving 16.4 feet (5 meters) in height in situ, and a tree canopy cover of 5 to 10 percent. When combined with shrubs and bushes these areas may achieve overall cover greater than 10 percent woody vegetation. Trees are defined as woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. These areas do not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

**** Reserved Forestland is defined as, "Land permanently reserved from wood products utilization through statute or administrative designation. Examples include National Forest wilderness areas and National Parks and Monuments." (U.S. Forest Service 2017a).

Softwoods constitute 56.9 percent of the US's timberlands growing stock (Table 2.6) (Oswalt et al. 2018). Most (66.8%) of the US's estimated 32,311 million dry tons of above ground biomass is in the boles of live trees with a diameter at breast height of 5 or more inches, 13.8% in the tops and limbs, and 3.6% in stumps (Oswalt et al. 2018). Saplings contain 11.4% of above ground biomass, sound dead biomass, which the U.S. Forest Service defines as salvageable dead trees, comprises 2.6% of all such biomass in the state, and woodland species contain 1.8 percent (U.S. Forest Service 2017a).

Table 2.6. United States Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 (Source: Oswalt et al. 2018 (Tables 17 and 38a)).

Growing Stock Volume ***(in million cubic feet)***			**Above Ground Biomass** ***(in million dry tons)***						
			Total Biomass	**Live Tree Biomass**					**Sound Dead Biomass**
				Trees Greater than 5-inches DBH			**Sapling Biomass**	**Woodland Species**	
Total	**Softwood**	**Hardwood**		**Boles**	**Stumps**	**Tops/Limbs**			
985,238	560,526	424,712	**32,311**	21,581	1,167	4,460	3,691	569	840

Data may not add to totals because of rounding.

In 2017, net growth exceeded mortality in US timberland by nearly 14,811 million cubic feet (Table 2.7), and net growth decreased 5.3 percent from 2011 to 2017 (Oswalt et al. 2014; 2018). Nearly 62 percent of net growth in 2017 occurred in softwoods (Table 2.7).

Table 2.7. United States Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in million cubic feet (Source: Oswalt et al. 2014; 2018 (Table 36)).

	All Species			**Softwoods**			**Hardwoods**		
	Net Growth*	**Removals**	**Mortality**	**Net Growth**	**Removals**	**Mortality**	**Net Growth**	**Removals**	**Mortality**
2011	26,413	12,854	9,015	15,663	8,319	5,162	10,750	4,535	3,843
2017	25,009	12,901	10,198	15,468	8,805	5,900	9,542	4,096	4,299

* "[N]et annual growth [is t]he average annual net increase in the volume of trees during the period between inventories. Components include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year and minus the net volume of trees that became cull trees during the year" (Oswalt 2014, 33). Thus, net annual growth includes mortality, but does not include removals, so removals must be subtracted from net growth to calculate increases or decreases in growing stock *in the forest*.

Non-industrial owners, also known as family forest owners, own 37.6 percent of US's timberlands and industrial landowners own 20.3 percent (Table 2.8) (Oswalt et al. 2018). Approximately 64 percent of the nation's timberlands are managed by public entities. Federal agencies administer 42.1 percent of the nation's timberlands, with the US government administering 31.1 percent of all timberlands, the states 9.2 percent, and counties and municipalities 1.8 percent.

Table 2.8. United States Timberland Area by Ownership, 2017, in thousands of acres (Source: Oswalt et al 2018 (Table 2)).

	Public					**Private**		**Total**
	Federal			**State**	**County & Municipal**	**Industrial**	**Non-Industrial**	
	National Forest	**BLM**	**Other**					
	144,868	37,559	55,433	70,464	13,687	155,748	287,733	
Subtotals	237,860							
Totals	322,011					443,481		**765,493**

Data may not add to totals because of rounding.

2.4.2. The Forest Industry

The majority (65.2%) of timber products manufactured in US were produced from softwoods (Table 2.9) (Source: Oswalt et al. 2014 (Table 39); Latta et al. 2018). Private non-industrial forests supplied the majority of softwood-based (56.2%) and hardwood-based (77.2%) feedstocks. Saw logs represented 38.8 percent (by volume) and pulpwood 36.2 percent of all of the state's timber products. Residential fuelwood (14.1%) were the only other product category using more than 10 percent of the nation's wood supply.

Table 2.9. United States Volume of Industrial Timber Products by Ownership Class and Timber Product, 2011, in millions of cubic feet (Source: Oswalt et al. 2014 (Table 39); Forest Service 2017b).

Ownership Class	Total	Saw Logs	Veneer Logs	Pulpwood	Composite Products	Residential Fuelwood*	Post-Poles-Pilings	Other Industrial
Softwoods								
National Forests	350,128	188,497	30,835	60,583	3,309	57,106	3,982	5,815
Other Public	651,666	350,843	35,769	182,438	9,251	48,501	10,584	14,280
Forest Industry	2,632,314	1,209,734	268,862	891,627	58,305	154,758	21,150	27,879
Other Private	4,679,270	1,853,372	288,408	1,952,019	193,157	253,092	44,469	94,752
Softwoods Total	8,313,378	3,602,446	623,874	3,086,667	264,022	513,457	80,185	142,726
Hardwoods								
National Forests	72,026	26,490	1,272	32,057	5,683	5,831	19	674
Other Public	542,334	130,652	7,111	174,133	34,640	188,801	450	6,547
Forest Industry	398,996	106,465	5,967	199,457	8,953	75,106	299	2,749
Other Private	3,426,477	1,077,724	61,546	1,128,528	91,391	1,018,168	2,215	46,907
Hardwoods Total	4,439,833	1,341,331	75,896	1,534,175	140,667	1,287,906	2,983	56,877
Total Softwoods and Hardwoods	12,753,211	4,943,777	699,770	4,620,842	404,689	1,801,363	83,168	199,603

Numbers in rows and columns may not add to totals due to rounding.

* Residential Fuelwood is consumed for private use (U.S. Department of Energy estimates). Industrial fuelwood included in Other Industrial.

2.5. Conclusion

As the following chapters indicate, forest biomass-based fuels generally provide a larger share of the five states examined in this report's energy mix than wood-derived fuels do for the US as a whole. The condition of these states' forest resources differs from that of the US because of their geographic location, forest resource composition, and land ownership patterns. While these states are not individually representative of the US, they are somewhat representative of states in their region of the US. Thus, the modeling results provided in the following chapters provides important lessons and insights that may be indicative of the impact of new bioenergy production on carbon emissions on neighboring states.

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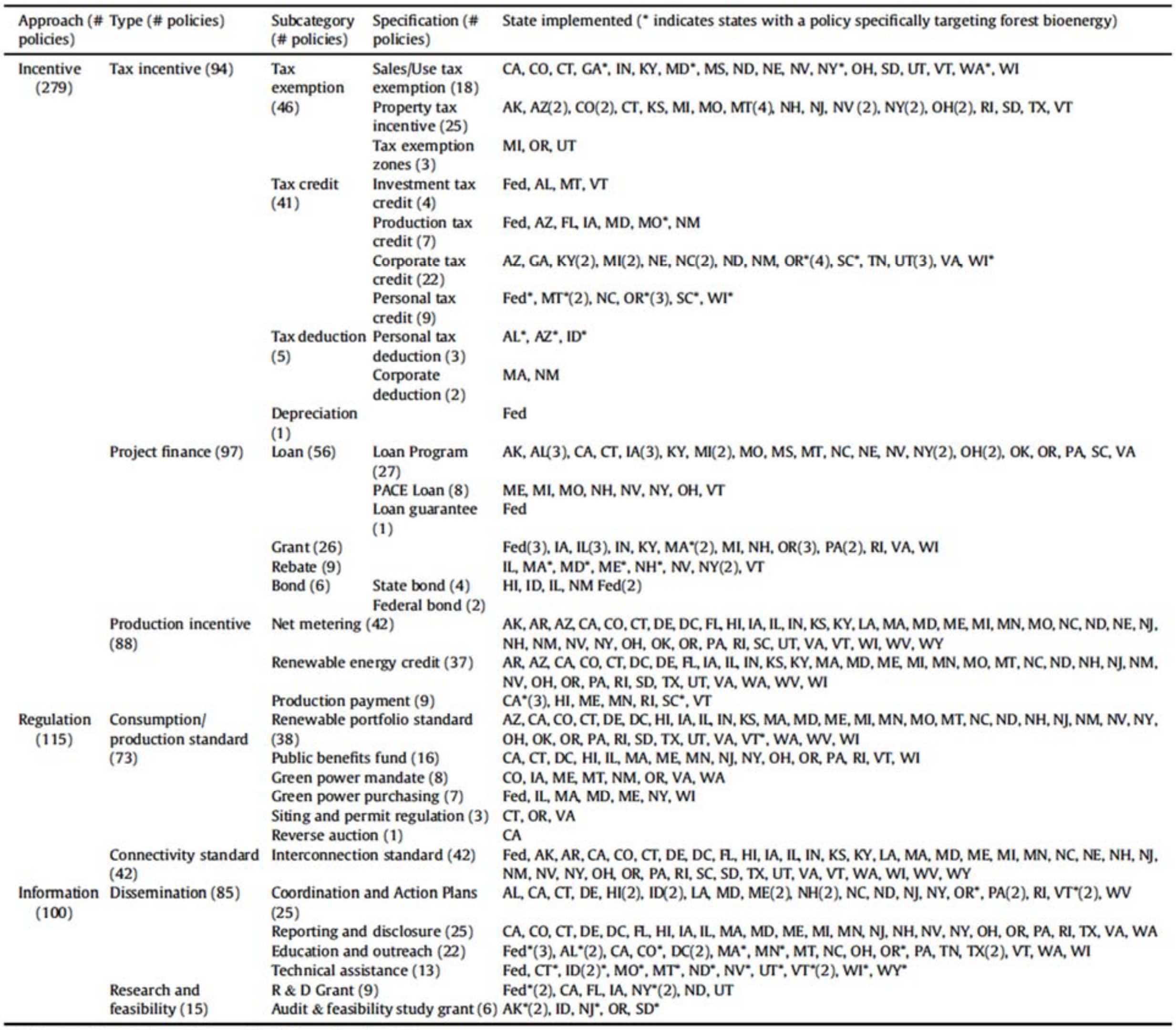
2.7. Appendix A:

Ebers et al. (2016) Classification of State's Policy Approaches for Forest Biomass Production.



Approach (# policies)	Type (# policies)	Subcategory (# policies)	Specification (# policies)	State implemented (* indicates states with a policy specifically targeting forest bioenergy)
Incentive (279)	Tax incentive (94)	Tax exemption (46)	Sales/Use tax exemption (18)	CA, CO, CT, GA*, IN, KY, MD*, MS, ND, NE, NV, NY*, OH, SD, UT, VT, WA*, WI
			Property tax incentive (25)	AK, AZ(2), CO(2), CT, KS, MI, MO, MT(4), NH, NJ, NV (2), NY(2), OH(2), RI, SD, TX, VT
			Tax exemption zones (3)	MI, OR, UT
		Tax credit (41)	Investment tax credit (4)	Fed, AL, MT, VT
			Production tax credit (7)	Fed, AZ, FL, IA, MD, MO*, NM
			Corporate tax credit (22)	AZ, GA, KY(2), MI(2), NE, NC(2), ND, NM, OR*(4), SC*, TN, UT(3), VA, WI*
			Personal tax credit (9)	Fed*, MT*(2), NC, OR*(3), SC*, WI*
		Tax deduction (5)	Personal tax deduction (3)	AL*, AZ*, ID*
			Corporate deduction (2)	MA, NM
		Depreciation (1)		Fed
	Project finance (97)	Loan (56)	Loan Program (27)	AK, AL(3), CA, CT, IA(3), KY, MI(2), MO, MS, MT, NC, NE, NV, NY(2), OH(2), OK, OR, PA, SC, VA
			PACE Loan (8)	ME, MI, MO, NH, NV, NY, OH, VT
			Loan guarantee (1)	Fed
		Grant (26)		Fed(3), IA, IL(3), IN, KY, MA*(2), MI, NH, OR(3), PA(2), RI, VA, WI
		Rebate (9)		IL, MA*, MD*, ME*, NH*, NV, NY(2), VT
		Bond (6)	State bond (4)	HI, ID, IL, NM Fed(2)
			Federal bond (2)	
	Production incentive (88)	Net metering (42)		AK, AR, AZ, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, NC, ND, NE, NJ, NH, NM, NV, NY, OH, OK, OR, PA, RI, SC, UT, VA, VT, WI, WV, WY
		Renewable energy credit (37)		AR, AZ, CA, CO, CT, DC, DE, FL, IA, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, OH, OR, PA, RI, SD, TX, UT, VA, WA, WV, WI
		Production payment (9)		CA*(3), HI, ME, MN, RI, SC*, VT
Regulation (115)	Consumption/ production standard (73)	Renewable portfolio standard (38)		AZ, CA, CO, CT, DE, DC, HI, IA, IL, IN, KS, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, NY, OH, OK, OR, PA, RI, SD, TX, UT, VA, VT*, WA, WV, WI
		Public benefits fund (16)		CA, CT, DC, HI, IL, MA, ME, MN, NJ, NY, OH, OR, PA, RI, VT, WI
		Green power mandate (8)		CO, IA, ME, MT, NM, OR, VA, WA
		Green power purchasing (7)		Fed, IL, MA, MD, ME, NY, WI
		Siting and permit regulation (3)		CT, OR, VA
		Reverse auction (1)		CA
	Connectivity standard (42)	Interconnection standard (42)		Fed, AK, AR, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, NC, NE, NH, NJ, NM, NV, NY, OH, OR, PA, RI, SC, SD, TX, UT, VA, VT, WA, WI, WV, WY
Information (100)	Dissemination (85)	Coordination and Action Plans (25)		AL, CA, CT, DE, HI(2), ID(2), LA, MD, ME(2), NH(2), NC, ND, NJ, NY, OR*, PA(2), RI, VT*(2), WV
		Reporting and disclosure (25)		CA, CO, CT, DE, DC, FL, HI, IA, IL, MA, MD, ME, MI, MN, NJ, NH, NV, NY, OH, OR, PA, RI, TX, VA, WA
		Education and outreach (22)		Fed*(3), AL*(2), CA, CO*, DC(2), MA*, MN*, MT, NC, OH, OR*, PA, TN, TX(2), VT, WA, WI
		Technical assistance (13)		Fed, CT*, ID(2)*, MO*, MT*, ND*, NV*, UT*, VT*(2), WI*, WY*
	Research and feasibility (15)	R & D Grant (9)		Fed*(2), CA, FL, IA, NY*(2), ND, UT
		Audit & feasibility study grant (6)		AK*(2), ID, NJ*, OR, SD*

* indicates states with a policy specifically targeting forest bioenergy.

3. Minnesota

3.1. Executive Summary

The impact of new bioenergy production on carbon emissions in Minnesota is a function of existing energy production and consumption, forest growth and respiration, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to establish the reference baseline condition for Minnesota. Net carbon emissions from adding new electricity generation using forest feedstocks is estimated from 2014 to 2035. The loss of existing bioenergy facilities is modeled for the same timeframe.

Model Parameters and Inputs

The Land Use and Resource Allocation (LURA) model is a forest products market projection system, solving for a recursive market equilibrium while accounting for the spatial detail associated with national forest resource base and forest products manufacturing base over time. The supply side of the model includes over 150,000 USDA Forest Service Forest Inventory and Analysis (FIA) forestland plots across the conterminous United States. Spatially disaggregated future supply is based on empirical yield functions for log volume, biomass and carbon. Demand data is based on a spatial database of over 2,500 forest product manufacturing facilities representing 11 intermediate and 13 final solid and pulpwood product categories.

The carbon emissions analyzed here are a function of landscape live-tree carbon and power plant emissions from the combustion of biomass for energy generation. Landscape carbon is based on (1) forest growth and respiration (i.e., forest structure is a function of change in age class over time, decay, mortality), (2) removals (e.g., harvests, timber stand improvement and restoration projects), and (3) fire, disturbance (e.g. hurricanes), insects, and diseases infestations. The location of carbon emissions is further influenced by forest products market dynamics driving competition and subsequent feedstock purchasing behavior. This dynamic will affect the location and intensity of forest harvesting, which affects subsequent forest growth and respiration, and probability of wildfire occurrence.

In consultation with Minnesota forestry and regulatory agencies, the nine scenarios set out below-were selected to model net change in carbon emissions from using forest feedstocks for electricity production at varying facility size, number, and location. Scenarios one through three ramp up the same configuration of electricity facilities equally scaled by location. Scenarios four through seven model one 20 MW facility in each of four locations. Scenario eight uses only logging residues for 20 MW facilities in each of four locations. Each new facility is assumed to begin operations in 2019 collocated with existing or recently closed facilities. Where feedstocks are constrained to logging residues, utilization is capped at 60% of available limbs, tops or defect resulting from forest harvesting operations. Other scenarios assume the allocation of sawlogs, pulpwood, and subsequent biomass is dictated by market dynamics. Scenario nine examines the impact of closing all seven existing bioenergy facilities in the state having a combined annual utilization of 1.02 million dry tons of biomass. Facility closures modeled to happen in 2019, a result of 2017 legislation to phase out state mandated agreements for biopower purchases.

Minnesota modeled scenarios of location, size, and feedstock.

Scenario	Cloquet	Bemidji	Grand Rapids	Brainerd	Key assumptions
Minnesota 1	50 MW	50 MW	50 MW	50 MW	
Minnesota 2	20 MW	20 MW	20 MW	20 MW	
Minnesota 3	10 MW	10 MW	10 MW	10 MW	
Minnesota 4	20 MW				
Minnesota 5		20 MW			
Minnesota 6			20 MW		
Minnesota 7				20 MW	Roundwood only
Minnesota 8	20 MW	20 MW	20 MW	20 MW	Logging residues only
Minnesota 9					Loss of 7 existing facilities

Model Scenarios Results

Emissions are expressed as an average annual net change in landscape live-tree carbon from 2014 to 2035 on an average annual MWh basis for electricity production. Net change is measured from the 2014 to 2035 baseline average values. We do not assume that forest biomass is carbon neutral. Rather, forest carbon is accounted for in real-time. A net increase in GHG emissions occurs when forest carbon storage in a bioenergy scenario is lower than that of the baseline. Alternatively, a net decrease in GHG emissions occurs when there is more forest carbon stored in the bioenergy scenario than in the baseline. In both bioenergy and baseline scenarios, forest carbon totals are aggregated from live tree, dead tree, understory, down dead, and forest floor pools.

As the table below notes, compared to the baseline, scenarios #3, #5, #7 averaged the lowest annual in-state emissions per MWh over the 17-year horizon. Scenario #1, which was modeled to illustrate how a significant increase in production (200 MW total) affects net emissions, had the largest impact where average annual in-state emissions were 658,187 t CO_2 or 0.63 t CO_2/MWh. In fact, there was a net decrease in emissions occurring outside Minnesota for all but scenario #7, which modeled roundwood feedstocks only, and #9 where all existing biopower production was shuttered in 2019. The larger shifts in biomass demand simulated in scenarios #1 and #9 require a longer time period of market adjustment with the -1 Mt reduction of Scenario #9 leading to higher landscape carbon stocks that stabilize after 2030 and the 1.3 Mt increase of Scenario #1 not quite stabilized by the end of the simulation in 2035.

The effect of constraining feedstocks to logging residues only is derived by comparing scenarios #2 and #8, each assuming new 20 MW electricity facilities in Cloquet, Bemidji, Grand Rapids, and Brainerd. The residuals only scenario (#8) had average annual in-state emissions of 52,250 t CO_2 or 0.12 t CO_2/MWh, whereas allowing markets to dictate allocation of sawlogs, pulpwood and biomass (scenario #2) had similar emissions of 62,524 t CO_2 or 0.15 t CO_2/MWh.

To understand the impact of any scenario, annual emissions from biomass need to be compared to annual emissions from the reference condition using fossil fuels to produce the same amount of energy (105,120 to 1,051,200 MWh/yr). Net change in projected forest carbon emissions were compared to the 10-year average in-state coal and natural gas carbon emissions to illustrate possible offsets by modeled scenario. Actual offsets would require comparison to future fossil fuel emissions. Positive values indicate a net displacement of fossil fuel emissions, or decline in total emissions; negative values indicate a net increase in total emissions as a result of the scenario. Results illustrate that total carbon emissions would be less for each biopower scenario when compared to the 10-year average fossil fuel alternative for all but scenario #1 natural gas (-11 t CO_2/MWh). The largest decline in emissions compared to coal is observed in scenario #5 (1.04 t CO_2/MWh) followed by scenarios #3 and #6 (0.98 t CO_2/MWh).

Another reference for comparing carbon emissions is to remove existing biopower facilities, which was modeled in scenario #9. All seven existing facilities were assumed closed in 2019 ranging in feedstock consumption from 21,000 to 312,000 dry tons/year (817,600 MWh/yr). The result was a net decrease in in-state annual emissions of -196,394 t CO_2 but an increase in out-of-state emissions of 218,071 t CO_2/MWh from decreased utilization of logging residues that would have otherwise decayed in the forest. Replacing that amount of lost biopower with coal or natural gas would result in a net increase in emissions of 0.87 t CO_2/MWh and 0.31 t CO_2/MWh, respectively.

Average annual net change in landscape live tree carbon emissions, 2019-2035.

Scenario	Feedstock consumption (t/yr)	Power plant emissions (tonnes CO2/yr)	Energy generation (MWh/yr)	Total live tree emissions (tCO2/yr)	Minnesota live tree emissions (tCO2/yr)	Minnesota live tree energy intensity (tCO2/MWh)	Net fossil fuel energy intensity displacement (tCO2/MWh)*	
							Coal	NG
Minnesota 1	1,314,000	2,407,248	1,051,200	528,131	658,187	0.63	0.45	-0.11
Minnesota 2	525,600	962,899	420,480	14,714	62,524	0.15	0.93	0.37
Minnesota 3	262,800	481,450	210,240	6,693	20,287	0.10	0.98	0.42
Minnesota 4	131,400	240,725	105,120	-5,713	21,584	0.21	0.87	0.31
Minnesota 5	131,400	240,725	105,120	-1,624	3,686	0.04	1.04	0.48
Minnesota 6	131,400	240,725	105,120	-3,086	10,447	0.10	0.98	0.42
Minnesota 7	131,400	240,725	105,120	21,290	14,501	0.14	0.94	0.38
Minnesota 8	525,600	962,899	420,480	-7,122	52,250	0.12	0.96	0.40
Minnesota 9	-1,022,000	-1,872,304	-817,600	21,677	-196,394	0.21	0.87	0.31

*Net change in average annual emissions comparing bioenergy scenarios (years 2019-2035) to coal and natural gas (NG) (years 2006-2015). Positive values indicate a net decrease in total emissions; negative values indicate a net increase in total emissions.

Conclusion

The impact of new bioenergy production on carbon emissions in Minnesota is most influenced by the scale of production and if existing facilities will stay open. Several scenarios yielded small increases in annual emissions over the 17-year horizon, which when combined with out-of-state emissions results in a net decline. Scenario #1 with significant increases in electricity generation would significantly increase in-state emissions while decreasing emissions outside Minnesota due to changing dynamics in forest products market competition. Constraining feedstocks to logging residues produced about the same emissions over the same number and size of facilities without constrained feedstocks. As reported, changes are projected to have direct effects on landscape forest carbon, but the total GHG implications of changes in energy systems requires that net forest emissions be compared against a reference condition in which fossil fuels or other generation technologies are used. Projected forest emissions were compared to the 10-year in-state coal and natural gas emissions (2006-2015) to illustrate possible carbon offsets by modeled scenario. But comparison to future fossil fuel emissions was beyond the scope of this analysis and remains an important area for further research.

3.2. Introduction

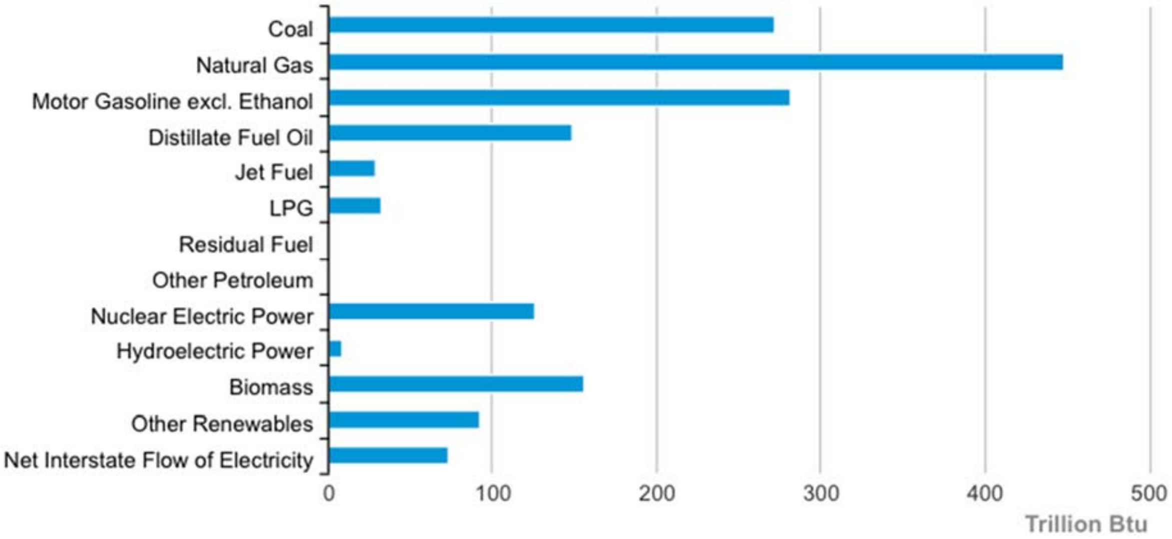
The impact of new bioenergy production on carbon emissions in Minnesota is a function of existing energy production and consumption, forest growth and respiration, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to establish the reference baseline condition for Minnesota. Net carbon emissions from adding new electricity generation using forest feedstocks is estimated from 2014 to 2035. The loss of existing bioenergy facilities is modeled for the same timeframe. These data may be used for establishing criteria for incorporating forest feedstocks into state and national greenhouse gas (GHG) accounting frameworks.

3.3. Minnesota Energy Profile

3.3.1. Energy Production and Consumption

State energy profiles are comprised of energy production, energy consumption, and energy imports, which are a function of price and availability.[9] In 2015, the most recent year comprehensive US Energy Information Agency (EIA) data are available,[10] Minnesota's primary energy production was limited to nuclear electricity power (125.9 trillion British Thermal Units (Btu)) and renewable energy (326.2 trillion Btu) (EIA 2017a, Table P2), namely hydroelectric power, biomass (including biofuels), and other renewables (EIA 2017a, Table P2; EIA 2017c). The state had no primary production of coal, natural gas, or crude oil (EIA 2017a, Table P2). Minnesota consumed 1,769.9 trillion Btu of energy in 2015 (Figure 3.1), of which 1,317.8 trillion Btu was produced from imports of primary energy production and their derivatives from other states (EIA 2017a, Table P3), including 72.7 trillion Btu imported in the form of electricity (EIA 2017b, Table C1).

Figure 3.1. Minnesota Energy Consumption Estimates, 2015 (Source: EIA 2017c).



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[9] Since energy prices are fairly volatile, this report does not include price information. Historic (1970-2015) energy price information is available at: https://www.eia.gov/state/seds/sep_prices/notes/pr_print.pdf.

[10] As of October 2017.

3.3.2. Electricity Production and Consumption

In 2015, Minnesota produced 57 million megawatt hours (MWh) of electricity (EIA 2016a), which was 7 percent more than produced in 2006 (Table 3.1). The majority of electricity was produced from fossil fuels, namely coal (43.3%) and natural gas (13%), with nuclear power providing 21.1 percent (EIA 2016a). Nearly 21 percent of electricity generated was from renewable energy, with wind providing 17.2 percent, wood and wood derived fuels adding 2.1 percent, and hydropower 1.5 percent (EIA 2016a). Total annual emissions across all energy sources averaged 0.62 tCO2/MWh. Coal derived energy produced the majority of emissions averaging 1.08 tCO2/MWh per year.

Table 3.1. Electricity Generation and Emissions for Minnesota, by Energy Source* (Source: EIA 2016a).

Year	Coal	Natural Gas	Nuclear	Wind	Wood and Wood Derived Fuels	Total**	CO2 Emissions (Mt CO2)	Energy Intensity (tCO2/MWh)
	Million megawatt hours							
2006	33.1	2.6	13.2	2.1	0.6	53.2	38.2	0.72
2007	32.2	3.8	13.1	2.6	0.7	54.5	38.3	0.70
2008	31.8	2.9	13.0	4.4	0.7	54.8	36.8	0.67
2009	29.3	2.8	12.4	5.1	0.8	52.5	33.7	0.64
2010	28.1	4.3	13.5	4.8	0.9	53.7	32.9	0.61
2011	28.3	3.4	12.0	6.7	0.7	53.1	32.6	0.61
2012	22.7	7.1	11.9	8.2	0.8	52.8	28.5	0.54
2013	23.5	6.3	10.7	8.3	1.0	51.3	29.3	0.57
2014	28.0	3.9	12.7	9.7	1.1	57.0	32.7	0.57
2015	24.7	7.4	12.0	9.8	1.2	57.0	30.3	0.53
	Energy intensity (tCO2/MWh)							
10-yr avg	1.08	0.52	0.0	0.0	0.0	0.62	--	--

* Table omits energy sources, other than "Wood and Wood Derived Fuels", that produced an average of 1 million MWh or less per year during these 10 years. This included "Other Biomass" and "Hydroelectric Conventional" (both of which produced an average of 0.7 million MWh/year), "Other" sources (averaged: 0.4 million MWh/year), "Petroleum" (averaged: 0.1 million MWh per year), and "Solar Thermal and Photovoltaic" and "Other Gases" (both of which averaged less than 0.1 million MWh/year).

** Row totals may not add up due to rounding and energy sources omitted in accordance with previous note.

Minnesota's electricity generators and combined heat and power (CHP) generators produced 57 million MWh of electricity in 2015. Electricity generators produced the vast majority of this (54.8 million MWh; 96.1% of all generation), of which electricity utilities generated 45.8 million MWh and independent power producers generated 9.0 million MWh (EIA 2016a). CHP facilities generated only 2.2 million MWh of the state's electricity – industrial power CHPs generated 1.5 million MWh, and electricity power CHPs and commercial power CHPs generated 0.5 million MWh and 0.2 million MWh, respectively (EIA 2016a).

Of the 66.6 million MWh of electricity consumed in Minnesota in 2015, 9.6 million MWh was imported (EIA 2016a; EIA 2016b). The state's commercial (35.1%), residential (32.6%), and industrial (32.2%) sectors consumed nearly equal amounts of this electricity (EIA 2016a). The transportation sector consumed less than 0.1 percent (EIA 2016b).

3.3.3. Electricity from Forest Biomass Resources. In 2015, net electricity generation from forest biomass, using EIA's Wood and Wood Derived Fuel definition,[11] provided more than 1.2 million MWh (2.1%) of Minnesota's electricity (Table 3.2) – and more than any other source besides coal, natural gas, nuclear, and wind (Table 3.1) (EIA 2016a). Forest biomass-based electricity generation nearly doubled from 2006 to 2015, with 48.1 percent of that electricity in 2015 produced by industrial power CHP facilities (EIA 2016a).

Table 3.2. 18 (Source: EIA 2016a).

Year	Combined Heat and Power			Electricity Generators		Total
	Industrial Power	Commercial Power	Electricity Power	Independent Power Producers	Electricity Utilities	
2006	493.1	0	76.9	0	19.7	**589.7**
2007	478.6	0	218.1	0	30.8	**727.5**
2008	466.1	0	208.6	0	50.5	**725.2**
2019	477.1	0	231.8	0	87.4	**796.3**
2010	511.6	0	159.1	0	261.9	**932.6**
2011	510.8	0	92.2	0	145.2	**748.2**
2012	491.9	0	212.6	0	134.7	**839.2**
2013	505.4	0	167.5	198.8	163.9	**1,035.6**
2014	531.1	11.7	202.5	256.6	147	**1,148.9**
2015	566.4	0.9	181.5	261.7	166.6	**1,177.2**

3.3.4. Biomass Thermal Heat Generation

In 2015, heat from wood, wood-derived fuels, and biomass waste[12] was used in Minnesota's residential, commercial, and industrial sectors (Table 3.3) (EIA 2017b). EIA estimated that thermal uses (45.7 trillion Btu) of these materials in the state were more than twice as much as the 22.5 trillion Btu from the use of this biomass to produce electricity (EIA 2017b, Tables CT3 and CT8),[13] and that Minnesota's thermal use of forest biomass increased 2.2 percent from 2006 to 2015.

Table 3.3. Minnesota Energy Consumption Estimates for Thermal and Electricity Power from "Wood, Wood-Derived Fuel, and Biomass Waste" by Year and Type of Producer in trillion Btu (Source: EIA 2017b, Tables CT2, CT3, CT4, CT5, CT6, CT8).

Year	Thermal Power (trillion Btu)	Electricity	Total

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[11] EIA (2017d) defines Wood and Wood-Derived Fuels as "Wood/Wood Waste Solids (including paper pellets, railroad ties, utility poles, wood chips, bark, and wood waste solids)[,] Wood Waste Liquids (excluding Black Liquor but including red liquor, sludge wood, spent sulfite liquor, and other wood-based liquids)[, and] Black Liquor. *Note:* EIA's (2017d) "Other Biomass" category includes other types of biomass, such as "Agricultural By-Products[,] Municipal Solid Waste[,] Other Biomass Gas (including digester gas, methane, and other biomass gases) [,] Other Biomass Liquids[,] Other Biomass Solids[,] Landfill Gas[, and] Sludge Waste. However, since this report's modeling focuses on forest biomass and its derivatives, this report focuses exclusively on EIA's Wood and Wood-Derived Fuels.

[12] EIA (2017d) defines biomass waste as "[o]rganic non-fossil material of biological origin that is a byproduct or a discarded product. Biomass waste includes municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural crop byproducts, straw, and other biomass solids, liquids, and gases; but excludes wood and wood-derived fuels (including black liquor), biofuels feedstock, biodiesel, and fuel ethanol. Note: EIA biomass waste data also include energy crops grown specifically for energy production, which would not normally constitute waste." *Note:* This definition differs from EIA's definition of "Other Biomass" – see previous footnote.

[13] "The electric power sector comprises electricity-only and combined-heat-and-power (CHP) plants ... whose primary business is to sell electricity, or electricity and heat, to the public" (EIA 2017b, 441).

	Residential Sector (thousand cords*)	Commercial Sector	Industrial Sector	Thermal Total	Power (trillion Btu)	Consumption (trillion Btu)
2006	9.5 (473)	2.2	33	44.7	8.9	**53.5**
2007	10.5 (523)	2.2	33.6	46.3	17.2	**63.5**
2008	11.7 (585)	2.4	32.9	46.7	17.7	**64.7**
2009	14 (701)	2.5	32.1	48.6	20.9	**69.5**
2010	12.2 (612)	2.6	33.6	48.4	24.3	**72.7**
2011	12.5 (626)	2.5	31.8	46.7	21.4	**68.2**
2012	11.7 (584)	2.3	30.6	44.6	24.2	**68.8**
2013	16.1 (806)	2.6	28.8	47.5	20	**67.6**
2014	16.4 (821)	5.2	32	53.6	22.1	**75.7**
2015	12.2 (612)	5.1	28.4	45.7	22.5	**68.2**

* EIA only estimated cord wood usage for this sector (EIA 2017b, Table CT4).

3.3.5. State Energy Choices

State energy policy choices are based on local, state, regional, and national goals, such as economic development, energy security, energy reliability (e.g., base and peak load capacity), energy prices, and air pollution emissions, including greenhouse gas emissions. These policies influence states' energy mixes and can cause energy producers and consumers to favor one or more energy sources over others. As Ebers et al. (2016, 67) noted as of "September 2013, federal and state governments had created 494 policies to support production of electricity and heat from forest biomass." Building on Becker et al. (2011), Ebers et al. (2016, 67) developed "a four-tier classification structure to categorize policy instruments based on: approach (incentive, regulation, information), type (e.g. tax incentive), subcategory (e.g. tax exemption), and specification (e.g. sales tax exemption)" (see Appendix A).

In Minnesota, the most common policy approaches focused on stimulating forest biomass energy were education and outreach.[14] Other incentives specific to renewable energy, but not limited to electricity or heat produced from forest biomass, included net metering, renewable energy credits, production payments, renewable portfolio standard, public benefits fund, interconnection standards, and reporting and disclosure (Ebers et al. 2016).

3.3.6. Biomass Energy CO_2 and Other Emissions

State energy choices regarding fossil fuels and renewables to produce heat and electricity have CO_2 and other emission implications. Emissions from biomass energy generation vary greatly depending on the feedstock source, location, conversion efficiency, and other factors. Combining heat with electricity production significantly increases efficiency over standalone electricity production and reduces GHG emissions per unit of energy generation, while dried forest biomass (e.g., pellets and dried wood chips) generally provides higher conversion efficiencies than green wood chips (Schlamadinger et al. 1997). Feedstock proximity, which affects greenhouse gas emissions from biomass transportation also impacts emissions, with biomass facilities price- and volume-constrained based on feedstock availability and competition from other biomass users (Schlamadinger et al. 1997, Galik et al. 2009).

In 2015, electricity production from *all sources* in Minnesota produced an estimated 30.3 million metric tons of CO_2, 27,246 metric tons of SO_2, and 27,751 metric tons of NO_X (EIA 2016c). Of these emissions, wood and wood-derived fuels produced 16 percent of the state's SO_2 emissions and 9.1 percent of its NO_X emissions (Table 3.4) (EIA 2016c). Because the EIA follows current international convention and assumes that CO_2 "released through the combustion of energy or fuel derived from plants (bioenergy or

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[14] The policy approaches reported in this paragraph use Ebers et al.'s (2016, 70) policy names/terminology.

biofuels) is excluded from reported energy-related emissions" (EIA 2011), *none* of Minnesota's estimated CO_2 electricity emissions include CO_2 emissions from biomass.[15]

Table 3.4. Minnesota Estimated Emission from "Wood and Wood-Derived Fuel" by Type of Producer in metric tons (Source: EIA 2016c).

Year	Emission	Electric Utility	Independent Power Producers		Commercial		Industrial		Total
			Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	
2006	SO_2	4	0	27	0	0	0	4,055	**4,086**
	NO_x	66	0	187	0	0	0	1,082	**1,335**
2007	SO_2	1	0	90	0	0	0	4,113	**4,204**
	NO_x	62	0	694	0	0	0	1,086	**1,842**
2008	SO_2	9	0	61	0	0	0	4,135	**4,205**
	NO_x	110	0	479	0	0	0	1,167	**1,756**
2009	SO_2	127	0	107	0	0	0	3,990	**4,224**
	NO_x	547	0	780	0	0	0	1,132	**2,459**
2010	SO_2	89	0	74	0	0	0	4,140	**4,303**
	NO_x	872	0	548	0	0	0	1,531	**2,951**
2011	SO_2	241	0	40	0	0	0	4,190	**4,471**
	NO_x	780	0	297	0	0	0	1,477	**2,554**
2012	SO_2	189	0	44	0	0	0	4,214	**4,447**
	NO_x	705	0	261	0	0	0	1,342	**2,308**
2103	SO_2	53	20	36	0	0	2	3,846	**3,957**
	NO_x	392	168	141	0	0	87	1,516	**2,304**
2014	SO_2	53	23	45	0	7	0	4,369	**4,497**
	NO_x	333	238	163	0	196	0	1,679	**2,609**
2015	SO_2	60	23	41	0	11	0	4,237	**4,372**
	NO_x	392	249	148	0	246	0	1,492	**2,527**

While international convention and the EIA assume that "the CO_2 released from biofuel or bioenergy combustion … [is] fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy," (EIA 2011, 60) from a landscape perspective forests can be a CO_2 sink, CO_2 source, or carbon neutral (Malmsheimer et al. 2008). Forests are a CO_2 sink when live and dead vegetation, litter, and soil sequester more carbon than emitted, and forests are a carbon source when these emissions exceed sequestration rates (Wear and Coulston 2015). Management actions such as timber harvesting, or natural disturbances like wildfires affecting the CO_2 balance determines the extent to which a forest is a net sink or source of CO_2 to the atmosphere (Woodall et al. 2015). Carbon is also sequestered in harvested wood products, such as lumber and paper, which affects the CO_2 balance (EIA 2011; Malmsheimer et al. 2008). At the end of a products' useful life, the carbon is either released

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[15] As EIA notes, "According to current international convention, CO_2 released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions. The related fossil fuel emissions from the transportation and processing of the biological feedstocks are captured within overall energy sector emissions, but currently they are not allocated to the biofuels. Additionally, the CO_2 released from biofuel or bioenergy combustion is assumed to be fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy. However, analysts have debated whether the increased use of biomass energy may result in a loss of terrestrial carbon stocks and foregone future sequestration by natural vegetation. The initial loss of carbon stocks in natural vegetation cleared to grow biomass feedstocks and the foregone future removal of CO_2 are not captured in energy sector emissions. To capture the potential net emissions, the international convention for GHG inventories is to report the net carbon flux from land use change (such as when forests are converted to cropland to grow feedstocks) in the Land Use category. Although accounting for land use emissions is more challenging than for most of the other emissions sources, emissions and sequestration associated with domestic U.S. land use change should in principle be accounted for in this chapter of the inventory report. However, from a global greenhouse gas emissions perspective, the key uncertainty regarding aggregate net biogenic emissions is indirect land use change that occurs abroad." (EIA 2011).

directly into the atmosphere through burning and energy combustion (Malmsheimer et al. 2011; Miner et al. 2014), or natural decomposition or decay in landfills (Skog 2008).[16]

While most forest-based carbon is eventually released into the atmosphere, forest products and forest biomass energy provide documented benefits. As Malmsheimer et al. (2011, S9) described, "[f]orest products used in place of energy intensive materials such as metals, concrete and plastics (a) reduce carbon emissions (because forest products require less fossil fuel-based energy to produce), (b) store carbon (for a length of time based on products' use and disposal), and (c) provide biomass residuals (i.e., waste wood) that can be substituted for fossil fuels to produce energy. [In addition,] [f]ossil fuel–produced energy releases carbon into the atmosphere that has resided in the Earth for millions of years; forest biomass–based energy uses far less of the carbon stored in the Earth thereby reducing the flow of fossil fuel–based carbon emissions to the atmosphere."

3.3. Forest Sector Profile

3.4.1. The Condition of the Forest Resource

As a lower value commodity relative to sawlogs and other forest products, the availability of biomass for energy generation often depends on other forest products markets to generate sufficient financial return to enable biomass removal (Oswalt et al. 2018; Miner et al. 2014). These markets depend in large part on the condition of a state's forest resource, species composition, and forest products manufacturing base.

More than one-third (34.2%) of Minnesota is forested, and the number of acres has increased slightly since 2011 (Table 3.5) (Oswalt et al. 2014; 2018). Almost 95 percent of the state's timberlands – forests producing or capable of producing industrial wood, and not withdrawn from timber utilization – have natural origins, as opposed to being planted (Oswalt et al. 2018).

Table 3.5. Minnesota Land Area, by Year, in thousands of acres (Sources: Oswalt et al. 2014; 2018 (Table 1a)).

Year	**Total Land Area**	**Forestland***					**Woodland******	**Other Land**
		Total	**Timberland****		**Reserved*****	**Other**		
			Planted	**Natural Origin**				
2011	50,961	17,371	774	15,155	967	475	0	33,590
2017	50,961	17,413	876	14,827	1,267	443	0	33,549

* Forestland is defined as, "Land at least 120 feet (37 meters) wide and at least 1 acre (0.4 hectares) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. The definition here includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest land also includes transition zones, such as areas between forest and non-forest lands that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (37 meters) wide or an acre in size. Forest land does not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

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[16] As Malmsheimer et al. (2011, S30), noted "Of the wood products that enter solid waste disposal sites, more than three quarters of the carbon in solid wood and almost one-half of the carbon in paper is never released to the atmosphere … . The carbon that is released during decay takes many years to reach the atmosphere. For example, the 23% of the solid wood that does decay has a half-life of 29 years. Skog (2008) found that when paper is landfilled, the nonlignin component (56%) decays, leaving the lignin component (44%) as a long-term store in the landfill … . This nondegradable fraction varies by grade, from approximately 10% for bleached chemical pulp fibers to 85% for mechanical pulp fibers (US EPA 2006)."

** Timberland is defined as, "Forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. (Note: Areas qualifying as timberland are capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.)" (U.S. Forest Service 2017a).

*** Woodland is defined as, "a class of land which consists predominantly of stands of sparse woodland species such as juniper, pinyon juniper, mesquite and small stature hardwood species and are found in the arid to semiarid regions of the interior western United States. These areas must span more than 1 acre (0.4 hectares, have sparse trees capable of achieving 16.4 feet (5 meters) in height in situ, and a tree canopy cover of 5 to 10 percent. When combined with shrubs and bushes these areas may achieve overall cover greater than 10 percent woody vegetation. Trees are defined as woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. These areas do not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

**** Reserved Forestland is defined as, "Land permanently reserved from wood products utilization through statute or administrative designation. Examples include National Forest wilderness areas and National Parks and Monuments." (U.S. Forest Service 2017a).

Hardwoods constitute 65.3 percent of Minnesota's timberland growing stock (Table 3.6) (Oswalt et al. 2018). Most (61.3%) of the state's estimated 519 million dry tons of above ground biomass is in the boles of live trees with a diameter at breast height of 5 or more inches, 15.6% in the tops and limbs, and 3.7% in stumps (Oswalt et al. 2018). Saplings contain 15.8% of above ground biomass and sound dead biomass, which the U.S. Forest Service defines as salvageable dead trees, comprises 3.9% of all such biomass in the state (U.S. Forest Service 2017a).

Table 3.6. Minnesota Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 (Source: Oswalt et al. 2018 (Tables 17 and 38a)).

Growing Stock Volume *(in million cubic feet)*			**Above Ground Biomass** *(in million dry tons)*						
			Total Biomass	**Live Tree Biomass**					**Sound Dead Biomass**
				Greater than 5-inches DBH			**Sapling Biomass**	**Woodland Species**	
Total	**Softwood**	**Hardwood**		**Boles**	**Stumps**	**Tops/Limbs**			
15,615	5,411	10,204	519	318	19	81	82	0	20

Data may not add to totals because of rounding.

In 2017, net growth exceeded mortality and removals in Minnesota timberland by nearly 400 million cubic feet (Table 3.7), and net growth increased 8 percent from 2011 to 2017 (Oswalt et al. 2014; 2018). More than 63 percent of net growth in 2017 occurred in hardwoods, particularly aspen type (Table 3.7.).

Table 3.7. Minnesota Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in thousand cubic feet (Source: Oswalt et al. 2014; 2018 (Table 36)).

	All Species			**Softwoods**			**Hardwoods**		
	Net growth*	**Removals**	**Mortality**	**Net growth***	**Removals**	**Mortality**	**Net growth***	**Removals**	**Mortality**
2011	399,839	233,628	224,292	146,105	71,001	67,337	253,733	162,626	156,955
2017	370,184	218,289	251,362	142,489	68,990	70,120	227,695	149,299	181,243

* "[N]et annual growth [is t]he average annual net increase in the volume of trees during the period between inventories. Components include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year and minus the net volume of trees that became cull trees during the year" (Oswalt 2014, 33). Thus, net annual growth includes mortality, but does not include removals, so removals must be subtracted from net growth to calculate increases or decreases in growing stock *in the forest*.

Approximately 53 percent of Minnesota's timberlands are managed by public entities. State agencies administer 22.1 percent of all timberlands, federal agencies 16.3 percent, and counties and municipalities 14.8 percent (Table 3.8) (Oswalt et al. 2018). Non-industrial owners, also known as family forest owners, own 39.7 percent of Minnesota's timberlands, and industrial landowners own 7.1 percent.

Table 3.8. Minnesota Timberland Area by Ownership, 2017, in thousands of acres (Source: Oswalt et al 2018 (Table 2)).

	Public					**Private**		**Total**
	Federal			**State**	**County & Municipal**	**Industrial**	**Non-Industrial**	
	National Forest	**BLM**	**Other**					
	2,594	6	239	3,849	2,574	1,239	6,912	
Subtotals	2,839							
Totals	9,262					8,150		17,413

Data may not add to totals because of rounding.

3.4.2. The Forest Industry

More than 71 percent of timber products manufactured in Minnesota were produced from hardwoods (Table 3.9) (Source: Oswalt et al. 2014 (Table 39)). Private non-industrial forests supplied 54 percent of hardwood-based feedstocks. State and county forests supplied 45.2 percent of softwood-based feedstock. Pulpwood represented more than half (50.4%) (by volume) of all timber products. Saw logs (17.7%), residential fuelwood (16%), and composite products (13.6%) were the only other product categories using more than 10 percent of in-state wood supply.

Table 3.9. Minnesota Volume of Industrial Timber Products by Ownership Class and Timber Product, 2011, in millions of cubic feet (Source: Oswalt et al. 2014 (Table 39); Forest Service 2017b).

Ownership Class	**Total**	**Saw Logs**	**Veneer Logs**	**Pulpwood**	**Composite Products**	**Residential Fuelwood***	**Post-Poles-Pilings**	**Other Industrial**
Softwoods								
National Forests	**5,078**	2,007	55	2,836	110	0	23	46
Other Public	**30,790**	10,023	157	17,655	1,118	794	382	662
Forest Industry	**2,730**	802	11	1,728	51	44	39	56
Other Private	**29,539**	12,386	207	13,561	1,371	1,010	236	769
Softwoods Total	**68,137**	25,219	430	35,779	2,650	1,847	679	1,533
Hardwoods								
National Forests	**8,795**	674	312	5,794	1,993	0	0	22
Other Public	**65,141**	5,956	1,003	35,921	12,022	9,982	0	257
Forest Industry	**4,604**	373	63	3,076	537	537	0	19
Other Private	**92,056**	10,119	1,531	39,835	15,362	24,624	1	585
Hardwoods Total	**170,597**	17,122	2,908	84,625	29,915	35,143	1	883
Total Softwoods and Hardwoods	**238,734**	42,340	3,338	120,405	32,564	36,990	680	2,416

Numbers in rows and columns may not add to totals due to rounding.

* Residential Fuelwood is consumed for private use (U.S. Department of Energy estimates). Industrial fuelwood included in Other Industrial.

3.5. Forest CO_2 Modeling

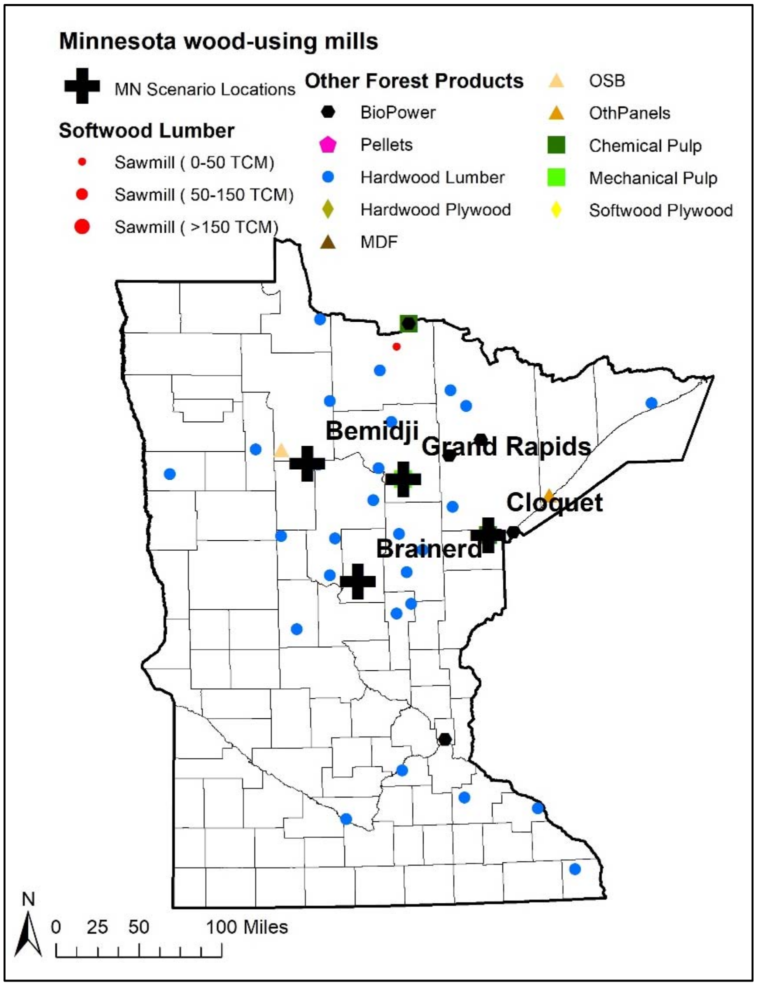
3.5.1. Model Parameters and Inputs

The Land Use and Resource Allocation (LURA) model is a forest products market projection system, solving for a recursive market equilibrium while accounting for the spatial detail associated with national forest resource base and forest products manufacturing base over time (Latta et al. 2018). The supply side of the model includes over 150,000 USDA Forest Service Forest Inventory and Analysis (FIA) plots across the conterminous United States. Spatially disaggregated future supply is based on empirical yield functions for log volume, biomass and carbon. Demand data is based on a spatial database of over 2,500 forest product manufacturing facilities representing 11 intermediate and 13 final solid and pulpwood product categories. Facility composition and distribution is presented in Figure 3.2 and Table 3.10.

Transportation costs are derived from fuel price and FIA plot location from which a log is harvested and mill or port destination. Trade among mills in intermediate products like sawmill residues or shavings is captured within the model formulation. The advantage of this modeling approach is that projections of forest harvest and carbon emissions incorporate changes in the local industrial makeup (new mills or products) directly allowing for evolving regional harvest-price-inventory relationships. LURA can model exogenous forest products demand through optimal allocation of primary and secondary forest derived commodities, or allocate exogenous harvest level across all forests and mills in the United States.

Future forest product demand is an exogenous variable set using key macroeconomic and energy market drivers from the 2015 Annual Energy Outlook (AEO) reference case (EIA, 2015). We do this directly, in the case of future biopower and co-firing levels, and indirectly through GDP, housing starts, and diesel prices. Figure 3.3 shows the projected annual change for solid wood products measured in million cubic meters (m^3), pulpwood products such as paper and pellets measured in million metric tonnes (Mt), and biopower measured in gigawatt hours (GWh). Future demand for solid wood products such as lumber, plywood, and panels demand is shaped in large part by the AEO2015 assumption that housing starts will continue to recover from 2008 recession levels through 2020, at which point they will level off and future demand growth will be primary GDP-related. On the pulpwood side, projected paper and pellet growth will initially decline

Figure 3.2. Minnesota Primary Wood-Using Mills and Bioenergy Expansion Scenario Locations, 2014 (Source: Latta et al. 2018).



with continued substitution away from newsprint and graphics paper to digital media (Latta et al, 2016), but with that effect muted over time as paperboard and pellet demand grows. While near term growth rates for non-scenario specific bioenergy expansion appear high they are accrued on a low initial level leading in little gain in overall forest product market share.

Harvests on private forestland in the United States are determined as log purchasers minimize costs to meet aggregate national demand. Public harvests are assumed to be policy, rather than market driven and are assumed to occur at 15-year average levels within the state, not to exceed the maximum county-level over the same time period. As all forest resource data are maintained in units of biomass, live-tree carbon is assumed to be one half of the biomass weight. Model projections focus on the facility-level implications of a change in biopower demand.

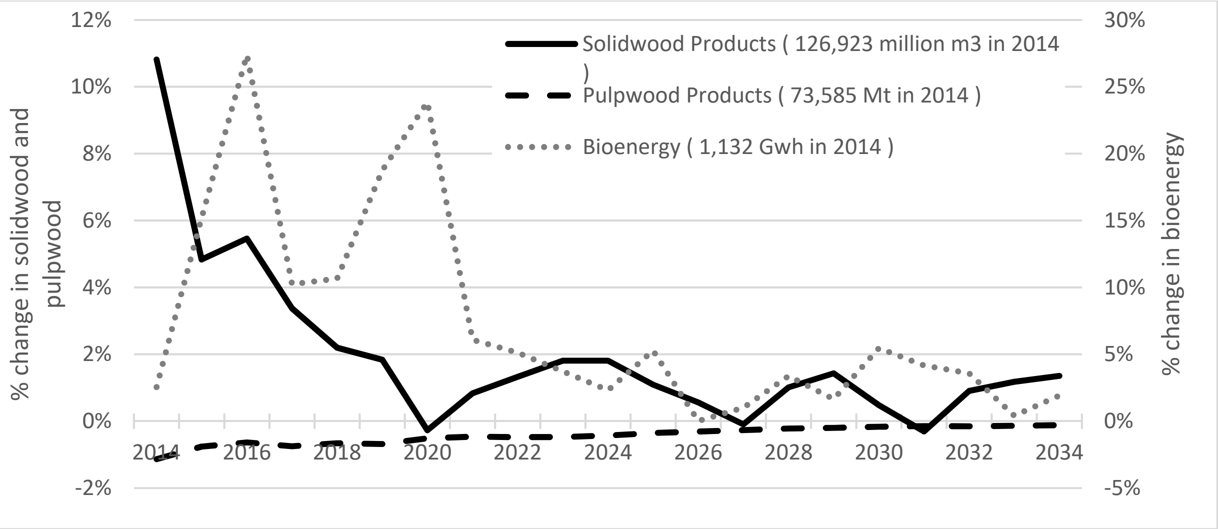
The effect of "leakage" on carbon emissions is important in at least two ways. First, in-state facilities may procure biomass from neighboring states, from which net changes in emissions are not captured in the Minnesota calculation. Second, facilities in neighboring states could procure biomass from Minnesota, which would shift Minnesota supply sources and prices. Therefore caution must be exercised when interpreting results where new facility impacts are limited to in-state forest emissions, which may under or overestimate net change. Finally, LURA is most appropriately used to project near-term dynamics, so estimates are only provided for the first 20 years (2015-2035) of alternative bioenergy scenarios.

Table 3.10. Total number of wood using facilities, production capacity, and foreign trade for wood products in Minnesota, 2014 (Source: Latta et al. 2018).

Forest Product		**Facilities**	**Capacity**	**Foreign trade***	
				Exports	**Imports**
		---- # ----	*----- million m^3 -----*	*---- million dollars ----*	
Roundwood	softwood			0.6	1.8
	hardwood			7.7	0.6
Lumber	softwood	3	158	2.1	966.6
	hardwood	27	283	37.8	967.2
Plywood	softwood			8.0	10.4
	hardwood	1	12		
Cross laminated timber (CLT)					
Oriented strand board (OSB)		1	531	4.8	129.2
Medium-density fibreboard (MDF)				0.1	1.6
Other panel products		2	287		
			-- million tonnes (Mt) --		
Pulp	chemical	2	842	6.1	829.5
	mechanical	1	225		
Newsprint				0.5	127.4
Print and writing paper		6	1,953	24.1	157.5
Paperboard		2	542	118.6	462.5
Tissue				1.4	1.1
Wood pellets				0.1	0.5
Chips	softwood			0.0	
	hardwood			0.0	
			------ MWh ------		
Forest biopower		7	33		
Forest co-firing		14	286		

*Port-level foreign trade data is 2010-2014 average from the United States International Trade Commission (USITC) Interactive Tariff and Trade Database (DataWeb), http://DataWeb.usitc.gov.

Figure 3.3. Projected change in national forest products industry production, 2014-2034.



3.5.2. Minnesota Model Scenarios

The carbon emissions analyzed here are a function of landscape live-tree carbon and power plant emissions from the combustion of biomass for energy generation. Landscape carbon is based on (1) forest growth and respiration (i.e., forest structure is a function of change in age class over time, decay, mortality), (2) removals (e.g., harvests, timber stand improvement and restoration projects), and (3) fire, disturbance (e.g. hurricanes), insects, and diseases infestations. The location of carbon emissions is further influenced by forest products market dynamics driving competition and subsequent feedstock purchasing behavior. This dynamic will affect the location and intensity of forest harvesting, which affects subsequent forest growth and respiration, and probability of wildfire occurrence. Total emissions are thus a function of the following variables, which form the basis for scenarios modeled in Minnesota:

- Facility size and location – influences where the feedstock is procured, distance traveled, and price paid. The number and size of competing forest products industries within a procurement zone subsequently influences price and the distribution of feedstock by end product.
- Number of facilities – affects the distribution of feedstock demand, distance traveled, and associated emissions.
- Feedstock availability – function of land ownership, tree characteristics (species, size, age, and location), and projected growth and yield. Factors such as insect and fire mortality, or policy regulations will affect average annual harvest levels and availability by ownership.
- Feedstock type – the carbon emissions profile is influenced by the type of feedstock used for energy production. For instance, the ratio of clear-cutting to harvest thinnings, or the ratio of pulpwood to logging residuals influences carbon flux.
- Product demand – total wood products demand for the United States is assumed unchanged when adding bioenergy capacity. Total exports also remain static but the distribution of port activity and regional production changes with any new bioenergy.
- Conversion technology – changing the type of biopower facility and rated efficiency will affect the volume of feedstock needed to produce energy, which affects emissions. The type of offset fossil fuel (e.g., coal-fired power) and corresponding conversation efficiency is important.

In consultation with Minnesota forestry and regulatory agencies, nine scenarios (Table 3.11) were selected to model net change in carbon emissions from using forest feedstocks for electricity production at varying facility size, number, and location (Figure 3.2). Scenarios one through three ramp up the same configuration of electricity facilities equally scaled by location. Scenarios four through seven model one 20 MW facility in each of four locations. Scenario eight uses only logging residues for 20 MW facilities in each of four locations. Each new facility is assumed to begin operations in 2019 collocated with existing or recently closed facilities. Where feedstocks are constrained to logging residues, utilization is capped at 60% of available limbs, tops or defect resulting from forest harvesting operations. The common practice and thus alternative fate in the region is burning residual piles resulting in instant emissions. Other scenarios assume the allocation of sawlogs, pulpwood, and subsequent biomass is dictated by market dynamics. Scenario nine examines the impact of closing all seven existing bioenergy facilities in the state having a combined annual utilization of 1.02 million dry tons of biomass. Facility closures are modeled to happen in 2019 a result of 2017 state legislation to phase out mandated biopower purchases.

For each scenario we assume feedstock requirements, heat rate, and annual generation are scalable based on a 20 MW electricity-only facility with a heat rate of 15,000 Btu/kWh (23% efficiency), a capacity factor of 60% and a feedstock higher heating value of 12 MMBtu/ton. One 20 MW facility would require 131,400 dry tons of biomass, produce 105,120 MWh annually, and have smokestack emissions of 240,900 t CO_2 (2.29 t CO_2/MWh). Scenarios were modeled independently (e.g., adding one 20 MW facility at a time) and assumed to be the only change in production.

Table 3.11. Minnesota modeled scenarios of location, size, and feedstock.

Scenario	Cloquet	Bemidji	Grand Rapids	Brainerd	Key assumptions
Minnesota 1	50 MW	50 MW	50 MW	50 MW	
Minnesota 2	20 MW	20 MW	20 MW	20 MW	
Minnesota 3	10 MW	10 MW	10 MW	10 MW	
Minnesota 4	20 MW				
Minnesota 5		20 MW			
Minnesota 6			20 MW		
Minnesota 7				20 MW	Roundwood only
Minnesota 8	20 MW	20 MW	20 MW	20 MW	Logging residues only
Minnesota 9					Loss of 7 existing facilities

3.5.3. Minnesota Model Scenarios Results

We used LURA to model a baseline reference case and the nine Minnesota scenarios. Emissions are expressed as an average annual net change in landscape live-tree carbon from 2014 to 2035 on a MWh basis for electricity production. Net change is measured from the 2014 to 2035 baseline average values. We do not assume that forest biomass is carbon neutral. Rather, forest carbon is accounted for in real-time. A net increase in GHG emissions occurs when forest carbon storage in a bioenergy scenario is lower than that of the baseline. Alternatively, a net decrease in GHG emissions occurs when there is more forest carbon stored in the bioenergy scenario than in the baseline. Forest carbon totals are aggregated from live tree, dead tree, understory, down dead, and forest floor pools.

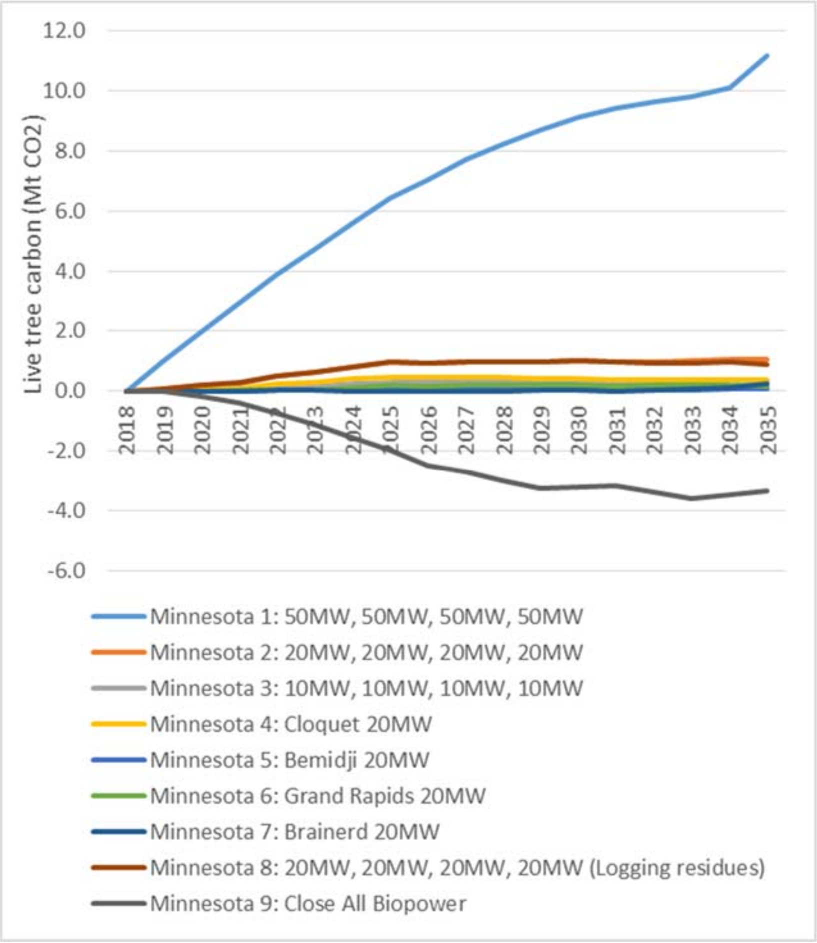
To fully understand the magnitude of biopower on net emissions, it is important to understand the overall trends in forest inventories in the baseline reference. The LURA model projects forest inventories to increase across the United States, but at a decreasing rate as a result of a slight decline in net growth. In Minnesota, the average forest carbon sequestration rate in the final five years of the baseline simulation

(2031 to 2035) is 75% lower than that of the first five years (2015 to 2019), while at the national level the difference between sequestration over those same two periods is -46%. This reduction in sequestration is due in part to higher near term harvest increases associated with the revival of housing construction across the US and in part to the aging of Northeastern and western federal forests. These trends are robust across scenarios, suggesting that net changes in landscape carbon emissions are more a function of larger resource and market dynamics, and have less to do with the operation of bioenergy facilities in Minnesota, at least at the scales modeled.

Compared to the baseline, scenarios #3, #5, #7 averaged the lowest annual in-state emissions per MWh over the 17-year horizon (Table 3.12). Scenario #1, which was modeled to illustrate how a significant increase in production (200 MW total) affects net emissions, had the largest impact where average annual in-state emissions were 658,187 t CO_2 or 0.63 t CO_2/MWh. The annual change in emissions occurring outside Minnesota for scenario #1 averaged -130,357 t CO_2, which indicates increased in-state utilization of harvest residues and other feedstocks. In fact, there was a net decrease in emissions occurring outside Minnesota for all but scenario #7, which modeled roundwood feedstocks only, and #9 where all existing biopower production was shuttered in 2019.

For all but scenarios #1 and #9, cumulative carbon stock change[17] depicted in Figure 3.4 shows an initial period of little change prior to scenario facility production coming online in 2019 followed by increased emissions rates from 2019 to 2025 as local harvest patterns adjust to the new biomass demand. The remainder of the time horizon the live-tree carbon stock level out just below stocks just after facility production began. The larger shifts in biomass demand simulated in scenarios #1 and #9 require a longer time period of market adjustment with the -1 Mt reduction of Scenario #9 leading to higher landscape carbon stocks that stabilize after 2030 and the 1.3 Mt increase of Scenario #1 not quite stabilized by the end of the simulation in 2035.

Figure 3.4. Cumulative carbon stock change from baseline for Minnesota scenarios, 2018 – 2035.



The effect of constraining feedstocks to logging residues only is derived by comparing scenarios #2 and #8, each assuming new 20 MW electricity facilities in Cloquet, Bemidji,

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[17] Change in cumulative carbon stock is calculated as the difference in the scenario carbon stock in a given year to the baseline carbon stocks in the same year.

Grand Rapids, and Brainerd. The residuals only scenario (#8) had average annual in-state emissions of 52,250 t CO_2 or 0.12 t CO_2/MWh, whereas allowing markets to dictate allocation of sawlogs, pulpwood and biomass (scenario #2) had similar emissions of 62,524 t CO_2 or 0.15 t CO_2/MWh. Out-of-state emissions decreased for both the residual only scenario (-59,372 t CO_2) and without constraints scenario (-47,810 t CO_2). Interestingly, total emissions for scenario #8 with four 20 MW facilities has a similar emissions profile as scenario #6 with one 20 MW facility in Grand Rapids. This illustrates how changes in feedstock composition and shifts in production have differential impacts, which is also observed in scenarios #4-7 where electricity generation is the same but in-state and out-of-state emissions vary. Hence, facility impacts are not scalable from one location another.

To understand the impact of any scenario, annual emissions from biomass need to be compared to annual emissions from the reference condition using fossil fuels to produce the same amount of energy (105,120 to 1,051,200 MWh/yr). Net change in projected forest carbon emissions were compared to the 10-year average in-state coal and natural gas carbon emissions (Table 3.1) to illustrate possible offsets by modeled scenario. Actual offsets would require comparison to future fossil fuel emissions. Positive values indicate a net displacement of fossil fuel emissions, or decline in total emissions; negative values indicate a net increase in total emissions as a result of the scenario. Results in Table 3.12 illustrate that total carbon emissions would be less for each biopower scenario when compared to the 10-year average fossil fuel alternative for all but scenario #1 natural gas (-11 t CO_2/MWh). The largest decline in emissions compared to coal is observed in scenario #5 (1.04 t CO_2/MWh) followed by scenarios #3 and #6 (0.98 t CO_2/MWh).

Another reference for comparing carbon emissions is to remove existing biopower facilities, which was modeled in scenario #9. All seven existing facilities were assumed closed in 2019 ranging in feedstock consumption from 21,000 to 312,000 dry tons/year (817,600 MWh/yr). The result was a net decrease in in-state annual emissions of -196,394 t CO_2 but an increase in out-of-state emissions of 218,071 t CO_2/MWh from decreased utilization of logging residues that would have otherwise decayed in the forest. Replacing that amount of lost biopower with coal or natural gas would result in a net increase in emissions of 0.87 t CO_2/MWh and 0.31 t CO_2/MWh, respectively.

Table 3.12. Average annual net change in landscape live tree carbon emissions, 2019-2035.

Scenario	Feedstock consumption (t/yr)	Power plant emissions (tonnes CO2/yr)	Energy generation (MWh/yr)	Total live tree emissions (tCO2/yr)	Minnesota live tree emissions (tCO2/yr)	Minnesota live tree energy intensity (tCO2/MWh)	Net fossil fuel energy intensity displacement (tCO2/MWh)*	
							Coal	NG
Minnesota 1	1,314,000	2,407,248	1,051,200	528,131	658,187	0.63	0.45	-0.11
Minnesota 2	525,600	962,899	420,480	14,714	62,524	0.15	0.93	0.37
Minnesota 3	262,800	481,450	210,240	6,693	20,287	0.10	0.98	0.42
Minnesota 4	131,400	240,725	105,120	-5,713	21,584	0.21	0.87	0.31
Minnesota 5	131,400	240,725	105,120	-1,624	3,686	0.04	1.04	0.48
Minnesota 6	131,400	240,725	105,120	-3,086	10,447	0.10	0.98	0.42
Minnesota 7	131,400	240,725	105,120	21,290	14,501	0.14	0.94	0.38
Minnesota 8	525,600	962,899	420,480	-7,122	52,250	0.12	0.96	0.40
Minnesota 9	-1,022,000	-1,872,304	-817,600	21,677	-196,394	0.21	0.87	0.31

*Net change in average annual emissions comparing bioenergy scenarios (years 2019-2035) to coal and natural gas (NG) (years 2006-2015). Positive values indicate a net decrease in total emissions; negative values indicate a net increase in total emissions. Observed average annual energy intensity of coal (1.08 tCO2/MWh) and natural gas (0.52 tCO2/MWh) are documented in Table 3.1.

3.6. Conclusion

The impact of new bioenergy production on carbon emissions in Minnesota is most influenced by the scale of production and if existing facilities will stay open. Several scenarios yielded small increases in annual emissions over the 17-year horizon (Table 3.12), which when combined with out-of-state emissions results in a net decline. Scenario #1 with significant increases in electricity generation would significantly increase in-state emissions while decreasing emissions outside Minnesota due to changing dynamics in forest products market competition. Constraining feedstocks to logging residues produced about the same emissions over the same number and size of facilities without constrained feedstocks. As reported, changes are projected to have direct effects on landscape forest carbon, but the total GHG implications of changes in energy systems requires that net forest emissions be compared against a reference condition in which fossil fuels or other generation technologies are used. Projected forest emissions were compared to the 10-year in-state coal and natural gas emissions (2006-2015) to illustrate possible carbon offsets by modeled scenario. But comparison to future fossil fuel emissions was beyond the scope of this analysis and remains an important area for further research.

3.7. References

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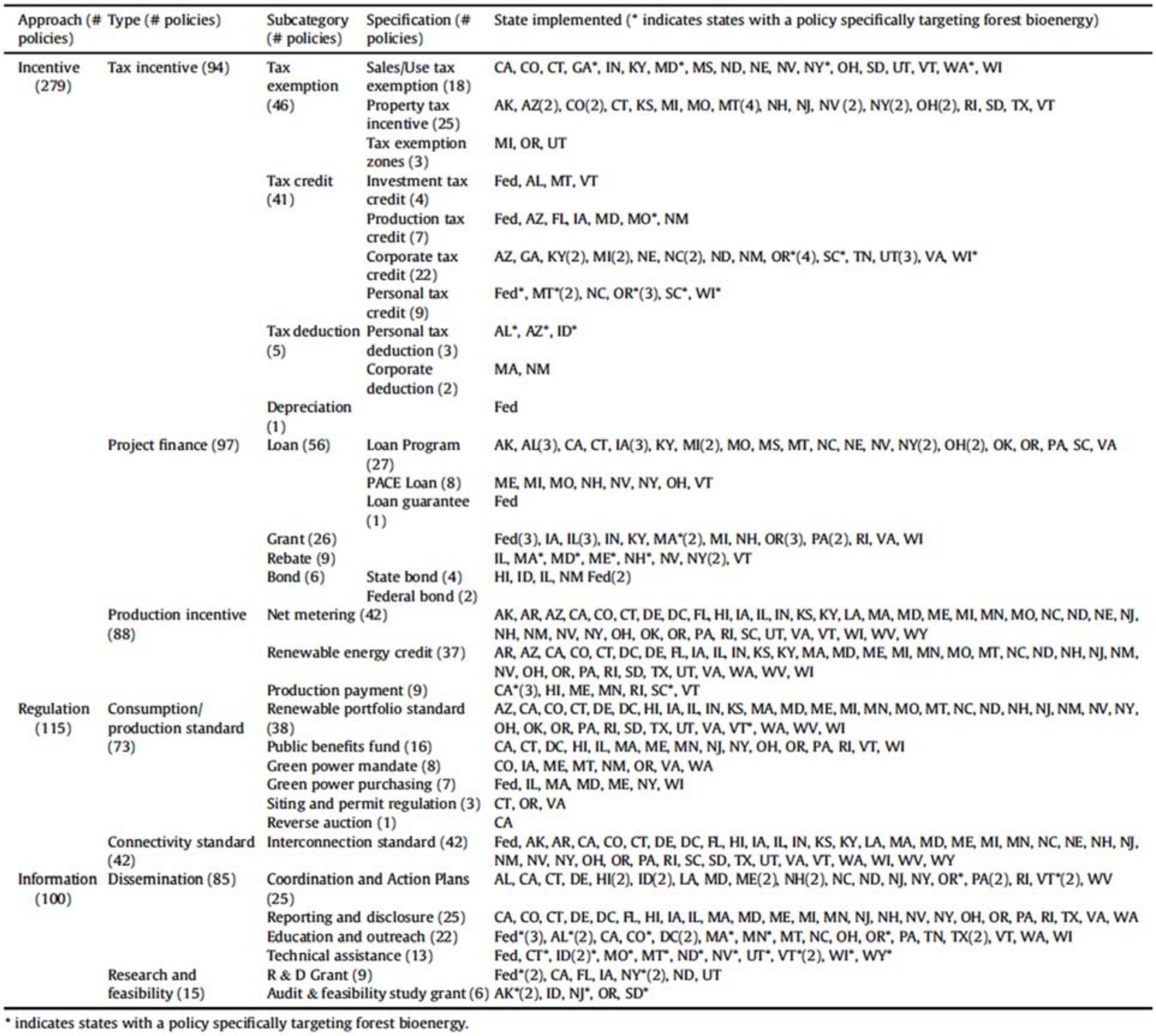
3.8. Appendix A:

Ebers et al. (2016) Classification of State's Policy Approaches for Forest Biomass Production.



Approach (# policies)	Type (# policies)	Subcategory (# policies)	Specification (# policies)	State implemented (* indicates states with a policy specifically targeting forest bioenergy)
Incentive (279)	Tax incentive (94)	Tax exemption (46)	Sales/Use tax exemption (18)	CA, CO, CT, GA*, IN, KY, MD*, MS, ND, NE, NV, NY*, OH, SD, UT, VT, WA*, WI
			Property tax incentive (25)	AK, AZ(2), CO(2), CT, KS, MI, MO, MT(4), NH, NJ, NV (2), NY(2), OH(2), RI, SD, TX, VT
			Tax exemption zones (3)	MI, OR, UT
		Tax credit (41)	Investment tax credit (4)	Fed, AL, MT, VT
			Production tax credit (7)	Fed, AZ, FL, IA, MD, MO*, NM
			Corporate tax credit (22)	AZ, GA, KY(2), MI(2), NE, NC(2), ND, NM, OR*(4), SC*, TN, UT(3), VA, WI*
			Personal tax credit (9)	Fed*, MT*(2), NC, OR*(3), SC*, WI*
		Tax deduction (5)	Personal tax deduction (3)	AL*, AZ*, ID*
			Corporate deduction (2)	MA, NM
		Depreciation (1)		Fed
	Project finance (97)	Loan (56)	Loan Program (27)	AK, AL(3), CA, CT, IA(3), KY, MI(2), MO, MS, MT, NC, NE, NV, NY(2), OH(2), OK, OR, PA, SC, VA
			PACE Loan (8)	ME, MI, MO, NH, NV, NY, OH, VT
			Loan guarantee (1)	Fed
		Grant (26)		Fed(3), IA, IL(3), IN, KY, MA*(2), MI, NH, OR(3), PA(2), RI, VA, WI
		Rebate (9)		IL, MA*, MD*, ME*, NH*, NV, NY(2), VT
		Bond (6)	State bond (4)	HI, ID, IL, NM Fed(2)
			Federal bond (2)	
	Production incentive (88)	Net metering (42)		AK, AR, AZ, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, NC, ND, NE, NJ, NH, NM, NV, NY, OH, OK, OR, PA, RI, SC, UT, VA, VT, WI, WV, WY
		Renewable energy credit (37)		AR, AZ, CA, CO, CT, DC, DE, FL, IA, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, OH, OR, PA, RI, SD, TX, UT, VA, WA, WV, WI
		Production payment (9)		CA*(3), HI, ME, MN, RI, SC*, VT
Regulation (115)	Consumption/ production standard (73)	Renewable portfolio standard (38)		AZ, CA, CO, CT, DE, DC, HI, IA, IL, IN, KS, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, NY, OH, OK, OR, PA, RI, SD, TX, UT, VA, VT*, WA, WV, WI
		Public benefits fund (16)		CA, CT, DC, HI, IL, MA, ME, MN, NJ, NY, OH, OR, PA, RI, VT, WI
		Green power mandate (8)		CO, IA, ME, MT, NM, OR, VA, WA
		Green power purchasing (7)		Fed, IL, MA, MD, ME, NY, WI
		Siting and permit regulation (3)		CT, OR, VA
		Reverse auction (1)		CA
	Connectivity standard (42)	Interconnection standard (42)		Fed, AK, AR, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, NC, NE, NH, NJ, NM, NV, NY, OH, OR, PA, RI, SC, SD, TX, UT, VA, VT, WA, WI, WV, WY
Information (100)	Dissemination (85)	Coordination and Action Plans (25)		AL, CA, CT, DE, HI(2), ID(2), LA, MD, ME(2), NH(2), NC, ND, NJ, NY, OR*, PA(2), RI, VT*(2), WV
		Reporting and disclosure (25)		CA, CO, CT, DE, DC, FL, HI, IA, IL, MA, MD, ME, MI, MN, NJ, NH, NV, NY, OH, OR, PA, RI, TX, VA, WA
		Education and outreach (22)		Fed*(3), AL*(2), CA, CO*, DC(2), MA*, MN*, MT, NC, OH, OR*, PA, TN, TX(2), VT, WA, WI
		Technical assistance (13)		Fed, CT*, ID(2)*, MO*, MT*, ND*, NV*, UT*, VT*(2), WI*, WY*
	Research and feasibility (15)	R & D Grant (9)		Fed*(2), CA, FL, IA, NY*(2), ND, UT
		Audit & feasibility study grant (6)		AK*(2), ID, NJ*, OR, SD*

* indicates states with a policy specifically targeting forest bioenergy.

4. Oregon

4.1 Executive Summary

The impact of new bioenergy production on carbon emissions in Oregon is a function of existing energy production and consumption, forest growth and respiration, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to establish the reference baseline condition for Oregon. Net carbon emissions from adding new electricity generation and pellet production using forest feedstocks is estimated from 2014 to 2035.

Model Parameters and Inputs

The Land Use and Resource Allocation (LURA) model is a forest products market projection system, solving for a recursive market equilibrium while accounting for the spatial detail associated with national forest resource base and forest products manufacturing base over time (Latta et al. 2018). The supply side of the model includes over 150,000 USDA Forest Service Forest Inventory and Analysis (FIA) forestland plots across the conterminous United States. Spatially disaggregated future supply is based on empirical yield functions for log volume, biomass and carbon. Demand data is based on a spatial database of over 2,500 forest product manufacturing facilities representing 11 intermediate and 13 final solid and pulpwood product categories.

The carbon emissions analyzed here are a function of landscape live-tree carbon and power plant emissions from the combustion of biomass for energy generation. Landscape carbon is based on (1) forest growth and respiration (i.e., forest structure is a function of change in age class over time, decay, mortality), (2) removals (e.g., harvests, timber stand improvement and restoration projects), and (3) fire, disturbance (e.g. hurricanes), insects, and diseases infestations. The location of carbon emissions is further influenced by forest products market dynamics driving competition and subsequent feedstock purchasing behavior. This dynamic will affect the location and intensity of forest harvesting, which affects subsequent forest growth and respiration, and probability of wildfire occurrence.

In consultation with Oregon forestry and regulatory agencies, the seven scenarios set out below were selected to model net change in carbon emissions from using forest feedstocks for energy production. Electricity generation is modeled for scenarios one through six varying facility size, number, and location. One new 200,000 dry ton pellet facility is modeled in scenario seven. Each new facility is assumed to begin operations in 2019 collocated with existing or recently closed facilities. Feedstocks are constrained to biomass from logging residues in four of the scenarios; the allocation of sawlogs, pulpwood, and biomass is dictated by market dynamics in the other three scenarios. Logging residue utilization is capped at 60% of available limbs, tops or defect resulting from forest harvesting operations reflecting the proportion available in piles.

We do not assume that forest biomass is carbon neutral. Rather, forest carbon is accounted for in real-time. A net increase in GHG emissions occurs when forest carbon storage in a bioenergy scenario is lower than that of the baseline. Alternatively, a net decrease in GHG emissions occurs when there is more forest carbon stored in the bioenergy scenario than in the baseline. In both bioenergy and baseline scenarios, forest carbon totals are aggregated from live tree, dead tree, understory, down dead, and forest floor pools.

Oregon modeled scenarios of potential facility location, size, and feedstock.

Scenario	La Grande	Klamath Falls	Roseburg	Warrenton	Coos Bay	Key Assumptions
Oregon 1	5 MW	10 MW	20 MW	20 MW		Logging residues only
Oregon 2	5 MW	10 MW	20 MW	20 MW		
Oregon 3	5 MW					Logging residues only
Oregon 4		10 MW				Logging residues only
Oregon 5			20 MW			
Oregon 6				20 MW		Logging residues only
Oregon 7					200,000 bdt	

Oregon Model Scenarios Results

Emissions are expressed as an average annual net change in landscape live-tree carbon from 2019 when the simulated facilities come online through 2035, and where applicable on an average annual MWh basis for electricity production. Net change is measured from the 2019 to 2035 baseline average values.

As the table below notes, compared to the baseline, the residual-only scenarios (#1,3,4,6) yielded the lowest average annual net emissions over the 17-year horizon. Scenario #1 with four new biomass electricity facilities of varying size and location was about 8% of scenario #2 in-state emissions with the same facilities but where biomass feedstocks were not constrained to logging residuals. The difference between scenarios #5 and #6 are greater, with and without logging residuals. By constraining feedstock supply to only logging residuals, and locating those facilities predominately in regions having high fire frequency, the modeled facility helps reduce fuel loads in places like La Grande and Klamath Falls by providing a viable market outlet, which affectively changes the probability of wildfire and subsequent wildfire emissions. The degree to which logging residues changes the emissions profile is based in large part on the degree to which the facility size is scaled appropriately to nearby wood products manufacturing and thus timber harvesting.

The influence of facility size is most apparent in scenario #2 where average annual live-tree emissions in Oregon were 44,628 t CO_2 or 0.15 t CO_2/MWh. Emissions occurring outside Oregon from shifts in production resulted in increased annual emissions of 32,805 t CO_2 for scenario #2; change in emissions outside Oregon for other scenarios were minimal or even negative. Dynamic forest product markets are causing ripple effects in competing industries, which changes the distribution of logging activity of the price industries are willing to pay for sawlogs, which drives the availability of biomass. The impact on carbon emissions is negligible for all but scenario #2.

As the effect of biomass demand on landscape forest carbon stocks is not dependent on its ultimate use the results from scenario #7 simulating an increase in biomass demand for wood pellet facility fits within the general pattern of results. As wood pellets require clean chips, logging residues were not considered as a feedstock choice and thus the landscape results most closely approximate that of scenario #5.

To understand the impact of any scenario, annual emissions from biomass need to be compared to annual emissions from the reference condition using fossil fuels to produce the same amount of energy (26,280 MWh/yr to 289,080 MWh/yr). Net change in projected forest carbon emissions were compared to the 10-year average in-state coal and natural gas carbon emissions to illustrate possible offsets by modeled scenario. Actual offsets would require comparison to future fossil fuel emissions. Positive values indicate a net displacement of fossil fuel emissions, or decline in total emissions; negative values indicate a net increase in total emissions as a result of the scenario. Results illustrate that total carbon emissions would be less for each biopower scenario when compared to the 10-year average fossil fuel alternative. The largest decline in emissions are observed comparing to coal power and range from 0.82 t CO_2/MWh (scenario #2) up to 0.97 t CO_2/MWh (scenario #6).

Table 4.12. Average annual net change in landscape live tree carbon emissions, 2019-2035.

Scenario	Feedstock consumption (t/yr)	Power plant emissions (tonnes CO2/yr)	Energy generation (MWh/yr)	Total live tree emissions (tCO2/yr)	Oregon live tree emissions (tCO2/yr)	Oregon live tree energy intensity (tCO2/MWh)	Net fossil fuel energy intensity displacement (tCO2/MWh)*	
							Coal	NG
Oregon 1	361,350	661,993	289,080	1,031	3,458	0.01	0.96	0.39
Oregon 2	361,350	661,993	289,080	77,433	44,628	0.15	0.82	0.25
Oregon 3	32,850	60,181	26,280	8,062	1,045	0.04	0.93	0.36
Oregon 4	65,700	120,362	52,560	590	1,242	0.02	0.95	0.38
Oregon 5	131,400	240,725	105,120	11,983	7,560	0.07	0.90	0.33
Oregon 6	131,400	240,725	105,120	64	(47)	0.00	0.97	0.40
Oregon 7	200,000	--	--	7,473	8,105	--	--	--

*Net change in average annual emissions comparing bioenergy scenarios (years 2019-2035) to coal and natural gas (NG) (years 2006-2015). Positive values indicate a net decrease in total emissions; negative values indicate a net increase in total emissions.

Conclusion

The impact of new bioenergy production on carbon emissions in Oregon is most influenced by whether or not feedstocks are constrained to logging residues, at least as the scales modeled. The residual-only scenarios yielded the lowest average annual net emissions over the 17-year horizon, and were less than 1 percent of the same facilities without constrained feedstocks. However, net annual emissions are negligible or even negative for all but scenario #2, suggesting that the scale of modeled production has little impact on statewide GHG profiles. Comparing results to the baseline condition from 2019 to 2035 also suggests that net emissions are more likely a function of changes in national resource conditions and market dynamics than with the operation of bioenergy facilities in Oregon. As reported, changes are projected to have direct effects on landscape forest carbon, but the total GHG implications of changes in energy systems requires that net forest emissions be compared against a reference condition in which fossil fuels or other generation technologies are used. Projected forest emissions were compared to the 10-year in-state coal and natural gas emissions (2006-2015) to illustrate possible carbon offsets by modeled scenario. But comparison to future fossil fuel emissions was beyond the scope of this analysis and remains an important area for further research.

4.2. Introduction

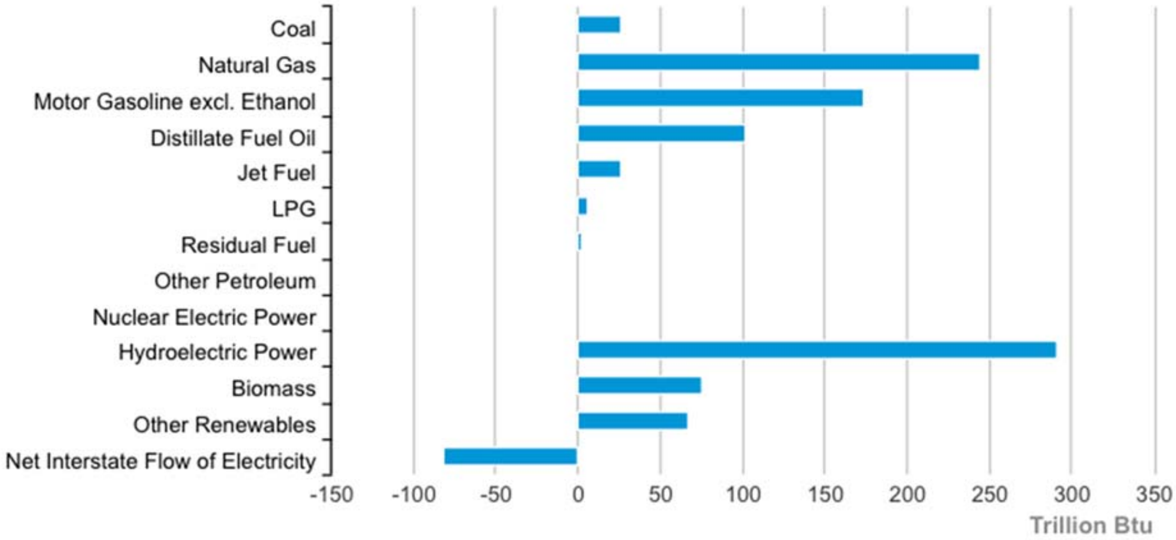
The impact of new bioenergy production on carbon emissions in Oregon is a function of existing energy production and consumption, forest growth and respiration, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to establish the reference baseline condition for Oregon. Net carbon emissions from adding new electricity generation and pellet production using forest feedstocks is estimated from 2014 to 2035. These data may be used for establishing criteria for incorporating forest feedstocks into state and national greenhouse gas (GHG) accounting frameworks.

4.3 Oregon Energy Profile

4.3.1. Energy Production and Consumption

States' energy profiles are comprised of energy production, energy consumption, and energy imports, which are a function of price and availability.[18] In 2015, the most recent year comprehensive US Energy Information Agency (EIA) data are available,[19] Oregon's primary energy production was limited to natural gas (0.9 trillion British Thermal Units (Btu)) and renewable energy (424.2 trillion Btu) (EIA 2017a, Table P2), namely hydroelectric power, biomass (including biofuels), and other renewables (EIA 2017a, Table P2; EIA 2017c). The state had no primary production of coal, nuclear electricity power, or crude oil (EIA 2017a, Table P2). Oregon consumed 956.7 trillion Btu of energy in 2015 (Figure 4.1), of which 531.6 trillion Btu was produced from imports of primary energy production and their derivatives from other states (EIA 2017a, Table P3). In 2015, using these imports and its own production, the state exported 81.7 trillion Btu in the form of electricity to other states (EIA 2017b, Table C1).

Figure 4.1. Oregon Energy Consumption Estimates, 2015 (Source: EIA 2017c)



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[18] Since energy prices are fairly volatile, this report does not include price information. Historic (1970-2015) energy price information is available at: https://www.eia.gov/state/seds/sep_prices/notes/pr_print.pdf.

[19] As of October 2017.

4.3.2. Electricity Production and Consumption

In 2015, Oregon produced 57.9 million megawatt hours (MWh) of electricity (EIA 2016a), which was 8.6 percent more than produced in 2006 (Table 4.1). The majority of that electricity was produced from fossil fuels, namely natural gas (28.1%) and coal (4.1%) (EIA 2016a). Nearly 67 percent of the electricity generated within the state was from renewable energy sources, with hydroelectric providing 54 percent, wind adding 11.5 percent, and wood and wood derived fuels providing 1.3 percent (EIA 2016a). Total annual emissions across all energy sources averaged 0.15 tCO2/MWh. Natural gas derived energy produced the majority of emissions averaging 0.40 tCO2/MWh per year.

Table 4.1. Electricity Generation and Emissions for Oregon, by Energy Source* (Source: EIA 2016a).

Year	Coal	Natural Gas	Hydro	Wind	Wood and Wood Derived Fuels	Total**	CO2 Emissions (Mt CO2)	Energy Intensity (tCO2/MWh)
	Million megawatt hours							
2006	2.4	11.2	37.9	0.9	0.8	53.3	7.2	0.13
2007	4.4	14.9	33.6	1.2	0.8	55.1	10.7	0.19
2008	4.0	17.4	33.8	2.6	0.7	58.7	10.8	0.18
2009	3.2	16.1	33	3.5	0.7	56.7	9.4	0.17
2010	4.1	15.7	30.5	3.9	0.6	55.1	10.1	0.18
2011	3.3	8.5	42.3	4.8	0.5	59.7	6.7	0.11
2012	2.6	11.6	39.4	6.3	0.6	60.9	7.4	0.12
2013	3.8	14.4	33.1	7.5	0.7	59.9	9.5	0.16
2014	3.2	12.7	35.3	7.6	0.8	60.1	8.4	0.14
2015	2.4	16.2	31.3	6.6	0.7	57.9	9.0	0.16
	Energy intensity (tCO2/MWh)							
10-yr avg	0.97	0.40	0.0	0.0	0.0	0.15	--	--

* Table omits energy sources, other than "Wood and Wood Derived Fuels", that produced an average of 1 million MWh or less per year during these 10 years. This included "Other Biomass" (produced an average of 0.2 million MWh/year), and "Petroleum", "Other Gases", "Geothermal", "Solar Thermal and Photovoltaic" and "Other" sources, (all of which averaged less than 0.1 million MWh per year).

** Row totals may not add up due to rounding and sources omitted in accordance with previous note.

Oregon's electricity generators and combined heat and power (CHP) generators produced 57.9 million MWh of electricity in 2015. Electricity generators produced the vast majority of this (52 million MWh; 89.8% of all generation), of which electric utilities generated 41.3 million MWh and independent power producers generated 10.7 million MWh (EIA 2016a). CHP facilities generated only 5.9 million MWh of the state's electricity – electricity power CHPs generated 5.1 million MWh, and industrial power CHPs and commercial power CHPs generated 0.7 million MWh and 0.1 million MWh, respectively (EIA 2016a).

Oregon consumed 47.3 million MWh of electricity and exported 10.6 million MWh in 2015 (EIA 2016a; EIA 2016b). The largest shares of electricity used within the state was by the residential (38.7%) and commercial (33.9%) sectors. The industrial sector consumed 27.4 percent and the transportation sector consumed only 0.1 percent of this electricity (EIA 2016b).

4.3.3. Electricity from Forest Biomass Resources. In 2015, net electricity generation from forest biomass, using EIA's Wood and Wood Derived Fuel definition,[20] provided more than 0.7 million MWh (1.2%) of Oregon's electricity (Table 4.2) – more than any other sources besides coal, natural gas, hydropower and wind (Table 4.1) (EIA 2016a). Forest biomass-based electricity generation decreased 6.5 percent from 2006 to 2015, with nearly 80 percent of that electricity in 2015 produced by industrial power CHP facilities (EIA 2016a).

Table 4.2. Oregon Net Generation from "Wood and Wood Derived Fuels" by Type of Producer and Year in thousand megawatt hours (Source: EIA 2016a).

Year	Combined Heat and Power			Electricity Generators		Total
	Industrial Power	Commercial Power	Electricity Power	Independent Power Producers	Electricity Utilities	
2006	508.6	0	290.2	0	0	**798.8**
2007	600.5	0	242	0	0	**842.6**
2008	500.8	0	216.3	0	0	**717.1**
2019	455.5	0	218.8	0	0	**674.4**
2010	462.4	0	169.6	0	0	**631.9**
2011	363.3	0	11.3	117.5	0	**492.1**
2012	472.4	0	0	127.7	0	**600.1**
2013	528.2	0	0	172	0	**700.2**
2014	607.4	0	0	195.2	0	**802.5**
2015	594.6	0	0	152.6	0	**747.2**

4.3.4. Biomass Thermal Heat Generation

In 2015, heat from wood, wood-derived fuels, and biomass waste[21] was used in Oregon's residential, commercial, and industrial sectors (Table 4.3) (EIA 2017b). EIA estimated that thermal uses (53.3 trillion Btu) of these materials in the state were 7.8 times greater than the 6.8 trillion Btu from the use of this biomass to produce electricity (EIA 2017b, Tables CT3 and CT8),[22] and that Oregon's thermal use of forest biomass increased 36.3 percent from 2006 to 2015.

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[20] EIA (2017d) defines Wood and Wood-Derived Fuels as "Wood/Wood Waste Solids (including paper pellets, railroad ties, utility poles, wood chips, bark, and wood waste solids)[,] Wood Waste Liquids (excluding Black Liquor but including red liquor, sludge wood, spent sulfite liquor, and other wood-based liquids)[, and] Black Liquor. *Note:* EIA's (2017d) "Other Biomass" category includes other types of biomass, such as "Agricultural By-Products[,] Municipal Solid Waste[,] Other Biomass Gas (including digester gas, methane, and other biomass gases) [,] Other Biomass Liquids[,] Other Biomass Solids[,] Landfill Gas[, and] Sludge Waste. However, since this report's modeling focuses on forest biomass and its derivatives, this report focuses exclusively on EIA's Wood and Wood-Derived Fuels.

[21] EIA (2017d) defines biomass waste as "[o]rganic non-fossil material of biological origin that is a byproduct or a discarded product. Biomass waste includes municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural crop byproducts, straw, and other biomass solids, liquids, and gases; but excludes wood and wood-derived fuels (including black liquor), biofuels feedstock, biodiesel, and fuel ethanol. Note: EIA biomass waste data also include energy crops grown specifically for energy production, which would not normally constitute waste." *Note:* This definition differs from EIA's definition of "Other Biomass" – see previous footnote.

[22] "The electric power sector comprises electricity-only and combined-heat-and-power (CHP) plants ... whose primary business is to sell electricity, or electricity and heat, to the public" (EIA 2017b, 441).

Table 4.3. Oregon Energy Consumption Estimates for Thermal and Electricity Power from "Wood, Wood-Derived Fuel, and Biomass Waste" by Year and Type of Producer in trillion Btu (Source: EIA 2017b, Tables CT2, CT3, CT4, CT5, CT6, CT8).

Year	Thermal Power (trillion Btu)				Electricity Power (trillion Btu)	Total Consumption (trillion Btu)
	Residential Sector (thousand cords*)	Commercial Sector	Industrial Sector	Thermal Total		
2006	8.8 (439)	1.6	28.8	39.1	7.4	**46.5**
2007	9.7 (486)	1.7	30.4	41.8	6.7	**48.5**
2008	10.9 (543)	1.9	26.1	38.9	4.5	**43.4**
2009	15.9 (796)	2.5	25.4	43.8	5.2	**49**
2010	13.9 (695)	2.5	25.3	41.6	5.4	**47**
2011	14.2 (710)	2.4	13.5	40.1	4.9	**45**
2012	13.3 (663)	2.1	29.4	44.8	5.3	**50**
2013	18.3 (916)	2.4	32	52.7	6.5	**59.2**
2014	18.6 (932)	2.5	30.9	52	7.7	**59.7**
2015	13.9 (694)	2.7	36.7	53.3	6.8	**60.2**

* EIA only estimated cord wood usage for this sector (EIA 2017b, Table CT4).

4.3.5. State Energy Choices

State energy policy choices are based upon goals like increasing economic development, energy security, energy reliability (e.g., base and peak load capacity), stabilizing energy prices, and reducing air pollution and GHG emissions. These policies influence states' energy mixes and can cause energy producers and consumers to favor one or more energy sources over others. As Ebers et al. (2016, 67) noted as of "September 2013, federal and state governments had created 494 policies to support production of electricity and heat from forest biomass." Building on Becker et al. (2011), Ebers et al. (2016, 67) developed "a four-tier classification structure to categorize policy instruments based on: approach (incentive, regulation, information), type (e.g. tax incentive), subcategory (e.g. tax exemption), and specification (e.g. sales tax exemption)" (see Appendix A).

In Oregon, the most common policy approaches focused on stimulating forest biomass energy were corporate and personal tax credits, coordination and action plans, and education and outreach.[23] Other incentives specific to renewable energy, but not limited to electricity or heat produced from forest biomass, included tax exemption zones, loan programs, grants, net metering, renewable energy credits, renewable portfolio standards, public benefits fund, siting and permit regulation, interconnection standard, reporting and disclosure, and audit and feasibility study grants (Ebers et al. 2016).

4.3.6. Biomass Energy CO_2 and Other Emissions

State energy choices regarding fossil fuels and renewables to produce heat and electricity have CO_2 and other emission implications. Emissions from biomass energy generation vary greatly depending on the feedstock source, location, conversion efficiency, and other factors. Combining heat with electricity production significantly increases efficiency over standalone electricity production and reduces GHG emissions per unit of energy generation, while dried forest biomass (e.g., pellets and dried wood chips) generally provides higher conversion efficiencies than green wood chips (Schlamadinger et al. 1997). Feedstock proximity, which affects greenhouse gas emissions from biomass transportation also impacts emissions, with biomass facilities price- and volume-constrained based on feedstock availability and competition from other biomass users (Schlamadinger et al. 1997, Galik et al. 2009).

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[23] The policy approaches reported in this paragraph use Ebers et al.'s (2016, 70) policy names/terminology.

In 2015, electricity production from *all sources* in Oregon produced an estimated 8.9 million metric tons of CO_2, 8,739 metric tons of SO_2, and 14,939 metric tons of NO_X (EIA 2016c). Of these emissions, wood and wood-derived fuels produced 51.9 percent of the state's SO_2 emissions, and 11 percent of its NO_X emissions (Table 4.4) (EIA 2016c). Because the EIA follows current international convention and assumes that CO_2 "released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions" (EIA 2011), *none* of Oregon's estimated CO_2 electricity emissions include CO_2 emissions from biomass.[24]

Table 4.4. Oregon Estimated Emission from "Wood and Wood-Derived Fuel" by Type of Producer in metric tons (Source: EIA 2016c).

Year	Emission	Electric Utility	Independent Power Producers		Commercial		Industrial		Total
			Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	
2006	SO_2	0	0	46	0	0	2	3,063	**3,111**
	NO_x	0	0	325	0	0	18	1,169	**1,512**
2007	SO_2	0	0	39	0	0	5	3,083	**3,127**
	NO_x	0	0	282	0	0	47	968	**1,297**
2008	SO_2	0	0	44	0	0	5	1,400	**1,449**
	NO_x	0	0	316	0	0	44	663	**1,024**
2009	SO_2	0	0	32	0	0	0	1,759	**1,791**
	NO_x	0	0	224	0	0	0	1,172	**1,396**
2010	SO_2	0	0	0	0	0	24	1,584	**1,608**
	NO_x	0	0	0	0	0	144	1,170	**1,314**
2011	SO_2	0	16	2	0	0	20	1,550	**1,588**
	NO_x	0	90	19	0	0	146	1,022	**1.277**
2012	SO_2	0	19	0	0	0	16	2,986	**3,021**
	NO_x	0	106	0	0	0	96	1,121	**1,323**
2103	SO_2	0	24	0	0	0	17	3,116	**3,157**
	NO_x	0	211	0	0	0	153	1,224	**1,588**
2014	SO_2	0	27	0	0	0	16	2,899	**2,942**
	NO_x	0	237	0	0	0	14	1,180	**1,431**
2015	SO_2	0	21	0	0	0	17	4,500	**4,538**
	NO_x	0	188	0	0	0	15	1,1447	**1,650**

While international convention and the EIA assume that "the CO_2 released from biofuel or bioenergy combustion … [is] fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy," (EIA 2011, 60) from a landscape perspective forests can be a CO_2 sink, CO_2 source, or carbon neutral (Malmsheimer et al. 2008). Forests are a CO_2 sink when live and dead vegetation, litter, and soil sequester more carbon than emitted, and forests are a carbon source when these emissions exceed sequestration rates (Wear and Coulston 2015). Management actions such as timber harvesting, or natural disturbances like wildfires affecting the CO_2 balance determines the extent

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[24] As EIA notes, "According to current international convention, CO_2 released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions. The related fossil fuel emissions from the transportation and processing of the biological feedstocks are captured within overall energy sector emissions, but currently they are not allocated to the biofuels. Additionally, the CO_2 released from biofuel or bioenergy combustion is assumed to be fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy. However, analysts have debated whether the increased use of biomass energy may result in a loss of terrestrial carbon stocks and foregone future sequestration by natural vegetation. The initial loss of carbon stocks in natural vegetation cleared to grow biomass feedstocks and the foregone future removal of CO_2 are not captured in energy sector emissions. To capture the potential net emissions, the international convention for GHG inventories is to report the net carbon flux from land use change (such as when forests are converted to cropland to grow feedstocks) in the Land Use category. Although accounting for land use emissions is more challenging than for most of the other emissions sources, emissions and sequestration associated with domestic U.S. land use change should in principle be accounted for in this chapter of the inventory report. However, from a global greenhouse gas emissions perspective, the key uncertainty regarding aggregate net biogenic emissions is indirect land use change that occurs abroad." (EIA 2011).

to which a forest is a net sink or source of CO_2 to the atmosphere (Woodall et al. 2015). Carbon is also sequestered in harvested wood products, such as lumber and paper, which affects the CO_2 balance (EIA 2011; Malmsheimer et al. 2008). At the end of a products' useful life, the carbon is either released directly into the atmosphere through burning and energy combustion (Malmsheimer et al. 2011; Miner et al. 2014), natural decomposition or decay in landfills (Skog 2008).[25]

While most forest-based carbon is eventually released into the atmosphere, forest products and forest biomass energy provide documented benefits. As Malmsheimer et al. (2011, S9) described, "[f]orest products used in place of energy intensive materials such as metals, concrete and plastics (a) reduce carbon emissions (because forest products require less fossil fuel-based energy to produce), (b) store carbon (for a length of time based on products' use and disposal), and (c) provide biomass residuals (i.e., waste wood) that can be substituted for fossil fuels to produce energy. [In addition,] [f]ossil fuel–produced energy releases carbon into the atmosphere that has resided in the Earth for millions of years; forest biomass–based energy uses far less of the carbon stored in the Earth thereby reducing the flow of fossil fuel–based carbon emissions to the atmosphere."

4.4. Forest Sector Profile

4.4.1. The Condition of the Forest Resource

As a lower value commodity relative to sawlogs and other forest products, the availability of biomass for energy generation often depends on traditional forest products markets to generate sufficient financial incentive to enable biomass removal (Oswalt et al. 2018; Miner et al. 2014). These markets depend in large part on the condition of a state's forest resource, species composition, and forest products manufacturing base.

Nearly half (48.3%) of Oregon is forested, and the number of acres has decreased slightly since 2011 (Table 4.5) (Oswalt et al. 2014; 2018). More than 72 percent of the state's timberlands – forests producing or capable of producing industrial wood, and not withdrawn from timber utilization – have natural origins, as opposed to being planted (Oswalt et al. 2018).

Table 4.5. Oregon Land Area, by Year, in thousands of acres (Sources: Oswalt et al. 2014; 2018 (Table 1a)).

Year	Total Land Area	Forestland*					Woodland****	Other Land
		Total	Timberland**		Reserved***	Other		
			Planted	Natural Origin				
2011	61,432	29,787	5,987	18,130	2,400	3,271	17	31,628
2017	61,432	29,653	6,537	17,131	2,818	3,167	73	31,706

* Forestland is defined as, "Land at least 120 feet (37 meters) wide and at least 1 acre (0.4 hectares) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. The definition here includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest land also includes transition zones, such as areas between forest and non-forest lands that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are

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[25] As Malmsheimer et al. (2011, S30), noted "Of the wood products that enter solid waste disposal sites, more than three quarters of the carbon in solid wood and almost one-half of the carbon in paper is never released to the atmosphere … . The carbon that is released during decay takes many years to reach the atmosphere. For example, the 23% of the solid wood that does decay has a half-life of 29 years. Skog (2008) found that when paper is landfilled, the nonlignin component (56%) decays, leaving the lignin component (44%) as a long-term store in the landfill … . This nondegradable fraction varies by grade, from approximately 10% for bleached chemical pulp fibers to 85% for mechanical pulp fibers (US EPA 2006)."

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classified as forest if they are less than 120 feet (37 meters) wide or an acre in size. Forest land does not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

** Timberland is defined as, "Forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. (Note: Areas qualifying as timberland are capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.)" (USDA Forest Service 2017a).

*** Woodland is defined as, "a class of land which consists predominantly of stands of sparse woodland species such as juniper, pinyon juniper, mesquite and small stature hardwood species and are found in the arid to semiarid regions of the interior western United States. These areas must span more than 1 acre (0.4 hectares, have sparse trees capable of achieving 16.4 feet (5 meters) in height in situ, and a tree canopy cover of 5 to 10 percent. When combined with shrubs and bushes these areas may achieve overall cover greater than 10 percent woody vegetation. Trees are defined as woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. These areas do not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

**** Reserved Forestland is defined as, "Land permanently reserved from wood products utilization through statute or administrative designation. Examples include National Forest wilderness areas and National Parks and Monuments." (USDA Forest Service 2017a).

Softwoods constitute 92.1 percent of Oregon's timberland growing stock (Table 4.6) (Oswalt et al. 2018). Most (77.5%) of the state's estimated 2,167 million dry tons of above ground biomass is in the boles of live trees with a diameter at breast height of 5 or more inches, 13.2% in the tops and limbs and 3.4% in stumps (Oswalt et al. 2018). Saplings contain 2.1% of above ground biomass and sound dead biomass, which the USDA Forest Service defines as salvageable dead trees, comprises 3.8% of all such biomass in the state (USDA Forest Service 2017a).

Table 4.6. Oregon Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 (Source: Oswalt et al. 2018 (Tables 17 and 38a)).

Growing Stock Volume *(in million cubic feet)*			**Above Ground Biomass *(in million dry tons)***						
			Total Biomass	**Live Tree Biomass**					**Sound Dead Biomass**
				Greater than 5-inches DBH			**Sapling Biomass**	**Woodland Species**	
Total	**Softwood**	**Hardwood**		**Boles**	**Stumps**	**Tops/Limbs**			
90,882	83,744	7,138	2,167	1,679	74	286	45	1	82

Data may not add to totals because of rounding.

In 2017, net growth exceeded mortality and removals in Oregon timberland by more than 2.1 billion cubic feet (Table 4.7), and net growth increased 23 percent from 2011 to 2017 (Oswalt et al. 2014; 2018). Ninety-two percent of net growth in 2017 occurred in softwoods (Table 4.7).

Table 4.7. Oregon Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in thousand cubic feet (Source: Oswalt et al. 2014; 2018 (Table 36)).

	All Species			**Softwoods**			**Hardwoods**		
	Net growth*	**Removals**	**Mortality**	**Net growth***	**Removals**	**Mortality**	**Net growth***	**Removals**	**Mortality**
2011	1,728,514	881,253	517,560	1,568,950	844,003	458,619	159,564	37,250	58,941
2017	2,126,666	1,086,584	544,018	1,956,885	1,042,823	463,732	169,781	43,761	80,285

* "[N]et annual growth [is t]he average annual net increase in the volume of trees during the period between inventories. Components include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year and minus the net volume of trees that became cull trees during the year" (Oswalt 2014, 33). Thus, net annual growth includes mortality, but does not include removals, so removals must be subtracted from net growth to calculate increases or decreases in growing stock *in the forest*.

Approximately 64 percent of Oregon's timberlands are managed by public entities. Federal agencies administer 60.2 percent of all timberlands, the State of Oregon 3.2 percent, and counties and municipalities 0.6 percent (Table 4.8) (Oswalt et al. 2018). Industrial landowners own 21.9 percent of Oregon's timberlands and non-industrial owners, also known as family forest owners, own 14.1 percent.

Table 4.8. Oregon Timberland Area by Ownership, 2017, in thousands of acres (Source: Oswalt et al 2018 (Table 2)).

	Public					Private		Total
	Federal			State	County & Municipal	Industrial	Non-Industrial	
	National Forest	BLM	Other					
	14,090	3,573	192	942	187	6,487	4,182	
Subtotals	17,856							
Totals	18,985					10,669		29,653

Data may not add to totals because of rounding.

4.4.2. The Forest Industry

The vast majority (95.9%) of timber products manufactured in Oregon were produced from softwoods (Table 4.9) (Source: Oswalt et al. 2014 (Table 39)). Private industrial forests supplied the majority of softwood-based (73.7%) and hardwood-based (92.8%) feedstocks. Saw logs represented 70.8 percent (by volume) of all of the state's timber products. Veneer logs (15.3%) was the only other product category using more than 10 percent of in-state wood supply.

Table 4.9. Oregon Volume of Industrial Timber Products by Ownership Class and Timber Product, 2011, in millions of cubic feet (Source: Oswalt et al. 2014 (Table 39); Forest Service 2017b).

Ownership Class	Total	Saw Logs	Veneer Logs	Pulpwood	Composite Products	Residential Fuelwood*	Post-Poles-Pilings	Other Industrial
				Softwoods				
National Forests	**65,937**	35,650	17,905	2,080	0	10,250	49	2
Other Public	**104,803**	85,787	14,269	1,220	0	3,526	1	0
Forest Industry	**636,190**	449,597	99,140	61,227	0	20,886	1,920	3,420
Other Private	**56,678**	45,480	6,505	2,162	0	1,851	325	355
Softwoods Total	**863,607**	616,515	137,819	66,689	0	36,512	2,295	3,778
				Hardwoods				
National Forests	**9**	9	0	0	0	0	0	0
Other Public	**99**	96	0	0	0	3	0	0
Forest Industry	**34,657**	19,720	0	14,105	0	832	0	0
Other Private	**2,569**	1,716	0	742	0	85	0	27
Hardwoods Total	**37,335**	21,541	0	14,847	0	920	0	27
Total Softwoods and Hardwoods	**900,942**	638,055	137,819	81,537	0	37,432	2,295	3,804

Numbers in rows and columns may not add to totals due to rounding.

* Residential Fuelwood is consumed for private use (U.S. Department of Energy estimates). Industrial fuelwood included in Other Industrial.

4.5. Forest CO_2 Modeling

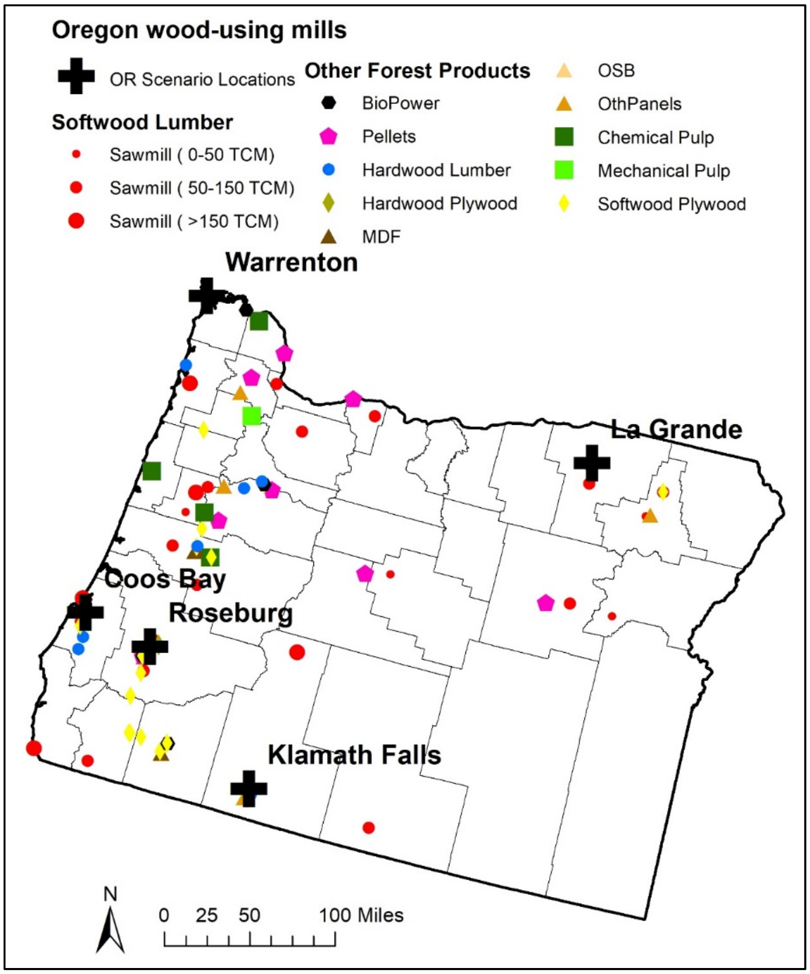
4.5.1. Model Parameters and Inputs

The Land Use and Resource Allocation (LURA) model is a forest products market projection system, solving for a recursive market equilibrium while accounting for the spatial detail associated with national forest resource base and forest products manufacturing base over time (Latta et al. 2018). The supply side of the model includes over 150,000 USDA Forest Service Forest Inventory and Analysis (FIA) plots across the conterminous United States. Spatially disaggregated future supply is based on empirical yield functions for log volume, biomass and carbon. Demand data is based on a spatial database of over 2,500 forest product manufacturing facilities representing 11 intermediate and 13 final solid and pulpwood product categories. Facility composition and distribution is presented in Figure 4.2 and Table 4.10.

Transportation costs are derived from fuel prices and the locations of FIA plot from which a log is harvested and mill or port destination. Trade among mills in intermediate products such as sawmill residues or planer shavings is captured within the model formulation. The advantage of this modeling approach is that projections of forest harvest and carbon emissions incorporate changes in the local industrial makeup (new mills or products) directly allowing for evolving regional harvest-price-inventory relationships. LURA can be used to either meet an exogenous forest products demand level through optimal allocation of primary and secondary forest derived commodities, or allocate an exogenous harvest level across all forests and mills in the United States.

Future forest product demand is an exogenous variable set using key macroeconomic and energy market drivers from the 2015 Annual Energy Outlook (AEO) reference case (EIA, 2015). We do this directly, in the case of future biopower and co-firing levels, and indirectly through GDP, housing starts, and diesel prices for other forest products. Figure 4.3 shows the projected annual change for solid wood products measured in million cubic meters (m^3), pulpwood products such as paper and pellets measured in million metric tonnes (Mt), and biopower measured in gigawatt hours (GWh). Future demand for solid wood products such as lumber, plywood, and panels is shaped in large part by the AEO2015 assumption that housing starts will continue to recover from 2008 recession levels through 2020, at which point they will level off and future demand growth will be primary GDP-related. On the pulpwood side, projected paper and pellet growth will initially decline with continued substitution away from newsprint and graphics paper to digital media (Latta et al, 2016), but with that effect muted over time as paperboard and pellet demand grows. While near term growth rates for non-scenario specific bioenergy expansion appear high they are accrued on a low initial level leading in little gain in overall forest product market share.

Figure 4.2. Oregon Primary Wood-Using Mills and Bioenergy Expansion Scenario Locations, 2014 (Source: Latta et al. 2018).



Harvests on private forestland in the United States are determined as log purchasers minimize costs to meet aggregate national demand. Public harvests are assumed to be policy, rather than market driven and are constrained to occur at 15-year average levels within the state, not to exceed the maximum county-level over the same time period. As all forest resource data are maintained in units of biomass, live-tree carbon is assumed to be one half of the biomass weight. Model projections focus on the facility-level implications of a change in biopower demand.

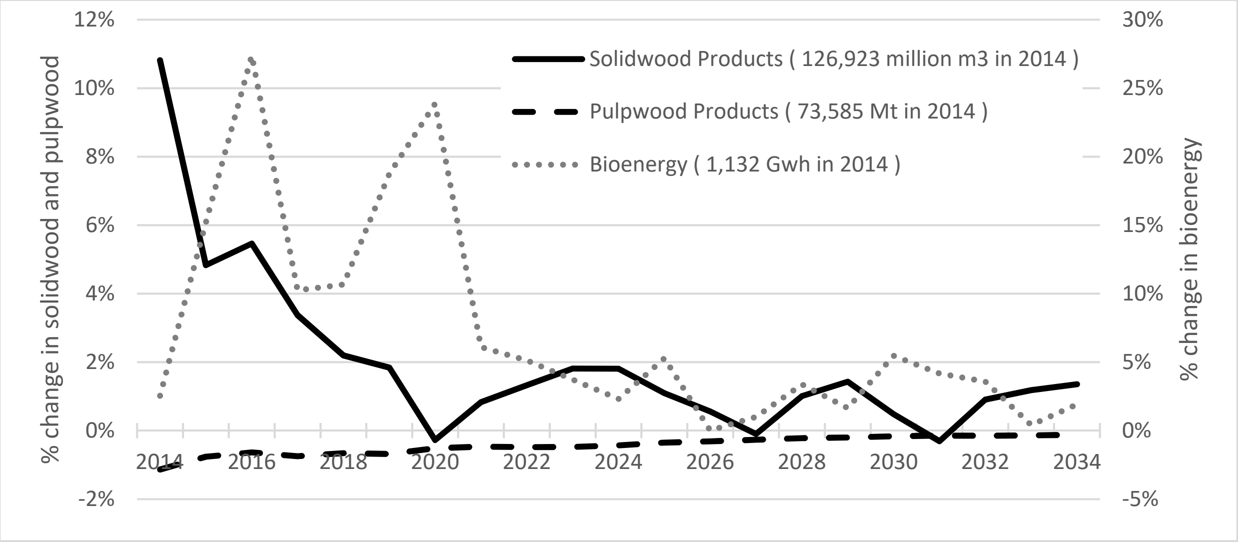
The effect of "leakage" on net carbon emissions is important in at least two ways. First, in-state facilities may procure biomass from neighboring states, from which net changes in emissions are not captured in the Oregon calculation. Second, facilities in neighboring states could procure biomass from Oregon, which would shift Oregon supply sources and market prices. Therefore caution must be exercised when interpreting results where new facility impacts are limited to in-state forest emissions, which may under or overestimate net change. Finally, LURA is most appropriately used to project near-term dynamics, so estimates are only provided for the first 20 years (2015-2035) of alternative bioenergy scenarios.

Table 4.10. Total number of wood using facilities, production capacity, and foreign trade for wood products in Oregon, 2014 (Source: Latta et al. 2018).

Forest Product		**Facilities**	**Capacity**	**Foreign trade***	
				Exports	**Imports**
		---- # ----	*----- million m^3 -----*	*---- million dollars ----*	
Roundwood	softwood			103.8	2.6
	hardwood			0.7	0.1
Lumber	softwood	56	10,108	34.0	5.4
	hardwood	7	312	44.2	10.5
Plywood	softwood	18	1,832	7.2	26.7
	hardwood	2	199		
Cross laminated timber (CLT)		1	28		
Oriented strand board (OSB)		0	0	0.0	
Medium-density fibreboard (MDF)		2	151	0.1	0.1
Other panel products		6	1456		
			-- million tonnes (Mt) --		
Pulp	chemical	4	1,759	64.5	2.2
	mechanical	1	250	0.0	1.3
Newsprint		1	226	10.1	
Print and writing paper		2	272	1.3	0.8
Paperboard		3	1,562	63.9	23.9
Tissue		3	504	0.9	0.3
Wood pellets		9	379	0.3	
Chips	softwood			90.1	0.0
	hardwood			0.0	0.0
			------ MWh ------		
Forest biopower		5	15		
Forest co-firing		1	41		

*Port-level foreign trade data is 2010-2014 average from the United States International Trade Commission (USITC) Interactive Tariff and Trade Database (DataWeb), http://DataWeb.usitc.gov. Foreign ports for Oregon include Astoria, Coos Bay, and Portland.

Figure 4.3. Projected change in national forest products industry production, 2014-2034.



4.5.2. Oregon Model Scenarios

The carbon emissions analyzed here are a function of landscape live-tree carbon and power plant emissions from the combustion of biomass for energy generation. Landscape carbon is based on (1) forest growth and respiration (i.e., forest structure is a function of change in age class over time, decay, mortality), (2) removals (e.g., harvests, timber stand improvement and restoration projects), and (3) fire, disturbance (e.g. hurricanes), insects, and diseases infestations. The location of carbon emissions is further influenced by forest products market dynamics driving competition and subsequent feedstock purchasing behavior. This dynamic will affect the location and intensity of forest harvesting, which affects subsequent forest growth and respiration, and probability of wildfire occurrence. Total emissions are thus a function of the following variables, which form the basis for the scenarios modeled in Oregon:

- Facility size and location – influences where the feedstock is procured, distance traveled, and price paid. The number and size of competing forest products industries within a procurement zone subsequently influences price and the distribution of feedstock by end product.
- Number of facilities – affects the distribution of feedstock demand, distance traveled, and associated emissions.
- Feedstock availability – function of land ownership, tree characteristics (species, size, age, and location), and projected growth and yield. Factors such as insect and fire mortality, or policy regulations will affect average annual harvest levels and availability by ownership.
- Feedstock type – the carbon emissions profile is influenced by the type of feedstock used for energy production. For instance, the ratio of clear-cutting to harvest thinnings, or the ratio of pulpwood to logging residuals influences carbon flux.
- Product demand – total wood products demand for the United States is assumed unchanged when adding bioenergy capacity. Total exports also remain static but the distribution of port activity and regional production changes with any new bioenergy.
- Conversion technology – changing the type of biopower facility and rated efficiency will affect the volume of feedstock needed to produce energy, which affects emissions. The type of offset fossil fuel (e.g., coal-fired power) and corresponding conversation efficiency is important.

In consultation with Oregon forestry and regulatory agencies, seven scenarios (Table 4.11) were selected to model net change in carbon emissions from using forest feedstocks for energy production. Electricity generation is modeled for scenarios one through six varying facility size, number, and location (Figure

4.2). One new 200,000 dry ton pellet facility is modeled in scenario seven. Each new facility is assumed to begin operations in 2019 collocated with existing or recently closed facilities. Feedstocks are constrained to biomass from logging residues in four of the scenarios; the allocation of sawlogs, pulpwood, and biomass is dictated by market dynamics in the other three scenarios. Logging residue utilization is capped at 60% of available limbs, tops or defect resulting from forest harvesting operations reflecting the proportion available in piles (Miller and Boston, 2017). The common practice and thus alternative fate in the region is burning residual piles resulting in instant emissions.

For each scenario we assume feedstock requirements, heat rate, and annual generation are scalable based on a 20 MW electricity-only facility with a heat rate of 15,000 Btu/kWh (23% efficiency), a capacity factor of 60% and a feedstock higher heating value of 12 MMBtu/ton. One 20 MW facility would require 131,400 dry tons of biomass, produce 105,120 MWh annually, and have smokestack emissions of 240,900 t CO_2 (2.29 t CO_2/MWh).

Table 4.11. Oregon modeled scenarios of potential facility location, size, and feedstock.

Scenario	La Grande	Klamath Falls	Roseburg	Warrenton	Coos Bay	Key Assumptions
Oregon 1	5 MW	10 MW	20 MW	20 MW		Logging residues only
Oregon 2	5 MW	10 MW	20 MW	20 MW		
Oregon 3	5 MW					Logging residues only
Oregon 4		10 MW				Logging residues only
Oregon 5			20 MW			
Oregon 6				20 MW		Logging residues only
Oregon 7					200,000 bdt	

4.5.3. Oregon Model Scenarios Results

We used LURA to model a baseline reference case and the seven Oregon scenarios over the 2014 to 2035 time period. Emissions are expressed as an average annual net change in landscape live-tree carbon from 2019 when the simulated facilities come online through 2035, and where applicable on a MWh basis for electricity production. Net change is measured from the 2019 to 2035 baseline average values.

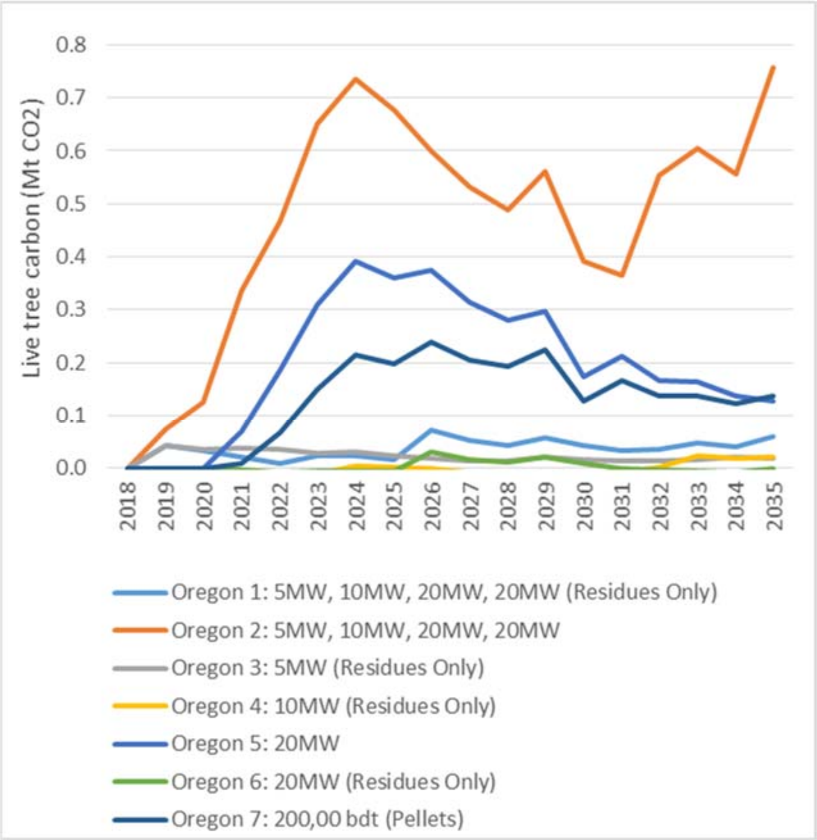
We do not assume that forest biomass is carbon neutral. Rather, forest carbon is accounted for in real-time. A net increase in GHG emissions occurs when forest carbon storage in a bioenergy scenario is lower than that of the baseline. Alternatively, a net decrease in GHG emissions occurs when there is more forest carbon stored in the bioenergy scenario than in the baseline. In both bioenergy and baseline scenarios, forest carbon totals are aggregated from live tree, dead tree, understory, down dead, and forest floor pools.

To fully understand the magnitude of biopower on net emissions, it is important to understand the overall trends in forest inventories in the baseline reference. The LURA model projects forest inventories to increase across the United States, but at a decreasing rate as a result of a slight decline in net growth. In Oregon, the average forest carbon sequestration rate in the final 5 years of the baseline simulation (2031 to 2035) is 27% lower than that of the first five years (2015 to 2019), while at the national level the difference between sequestration over those same two periods is -46%. This reduction in sequestration is due in part to higher near term harvest increases associated with the revival of housing construction and in part to the aging of Northeastern and western federal forests. These trends are robust across scenarios, suggesting that net changes in carbon emissions are more a function of larger resource and market dynamics, and have less to do with the operation of bioenergy facilities in Oregon, at least at the scales modeled.

Compared to the baseline, the residual-only scenarios (#1,3,4,6) yielded the lowest average annual net emissions over the 17-year horizon (Table 4.12). Scenario #1 with four new biomass electricity facilities of varying size and location was about 8% of scenario #2 in-state emissions with the same facilities but where biomass feedstocks were not constrained to logging residuals. The difference between scenarios #5 and #6 are greater, with and without logging residuals. By constraining feedstock supply to only logging residuals, and locating those facilities predominately in regions having high fire frequency, the modeled facility helps reduce fuel loads in places like La Grande and Klamath Falls by providing a viable market outlet, which affectively changes the probability of wildfire and subsequent wildfire emissions. The degree logging residues change the emissions profile is based in large part on the degree to which the facility size is scaled appropriately to nearby wood products manufacturing and thus timber harvesting.

The influence of facility size is most apparent in scenario #2 where average annual live-tree emissions in Oregon were 44,628 t CO_2 or 0.15 t CO_2/MWh. Emissions occurring outside Oregon from shifts in production resulted in increased annual emissions of 32,805 t CO_2 for scenario #2; change in emissions outside Oregon for other scenarios were minimal or even negative. Cumulative carbon stock change[26] depicted in Figure 4.4 shows an initial period of little change prior to facility production coming online in 2019 followed by increased emissions rates from 2019 to 2023 as local harvest patterns adjust to the new biomass demand. The remainder of the time horizon is punctuated by cycles of increased and decreased live-tree carbon averaging out at a lower level than just after facility production began. Dynamic forest product markets are causing ripple effects in competing industries, which changes the distribution of logging activity of the price industries are willing to pay for sawlogs, which drives the availability of biomass. The impact on landscape carbon emissions is negligible for all but scenario #2.

Figure 4.4. Cumulative carbon stock change from baseline for Oregon scenarios, 2018 – 2035.



As the effect of biomass demand on landscape forest carbon stocks is not dependent on its ultimate use the results from scenario #7 simulating an increase in biomass demand for wood pellet facility fits within the general pattern of results. As wood pellets require clean chips, logging residues were not considered as a feedstock choice and thus the landscape results most closely approximate that of scenario #5.

To understand the impact of any scenario, annual emissions from biomass need to be compared to annual emissions from the reference condition using fossil fuels to produce the same amount

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[26] Change in cumulative carbon stock is calculated as the difference in the scenario carbon stock in a given year to the baseline carbon stocks in the same year.

of energy (26,280 MWh/yr to 289,080 MWh/yr). Net change in projected forest carbon emissions were compared to the 10-year average in-state coal and natural gas carbon emissions (Table 4.1) to illustrate possible offsets by modeled scenario. Actual offsets would require comparison to future fossil fuel emissions. Positive values indicate a net displacement of fossil fuel emissions, or decline in total emissions; negative values indicate a net increase in total emissions as a result of the scenario. Results in Table 4.12 illustrate that total carbon emissions would be less for each biopower scenario when compared to the 10-year average fossil fuel alternative. The largest decline in emissions are observed comparing to coal power and range from 0.82 t CO_2/MWh (scenario #2) up to 0.97 t CO_2/MWh (scenario #6).

Table 4.12. Average annual net change in landscape live tree carbon emissions, 2019-2035.

Scenario	Feedstock consumption (t/yr)	Power plant emissions (tonnes CO2/yr)	Energy generation (MWh/yr)	Total live tree emissions (tCO2/yr)	Oregon live tree emissions (tCO2/yr)	Oregon live tree energy intensity (tCO2/MWh)	Net fossil fuel energy intensity displacement (tCO2/MWh)*	
							Coal	NG
Oregon 1	361,350	661,993	289,080	1,031	3,458	0.01	0.96	0.39
Oregon 2	361,350	661,993	289,080	77,433	44,628	0.15	0.82	0.25
Oregon 3	32,850	60,181	26,280	8,062	1,045	0.04	0.93	0.36
Oregon 4	65,700	120,362	52,560	590	1,242	0.02	0.95	0.38
Oregon 5	131,400	240,725	105,120	11,983	7,560	0.07	0.90	0.33
Oregon 6	131,400	240,725	105,120	64	(47)	0.00	0.97	0.40
Oregon 7	200,000	--	--	7,473	8,105	--	--	--

*Net change in average annual emissions comparing bioenergy scenarios (years 2019-2035) to coal and natural gas (NG) (years 2006-2015). Positive values indicate a net decrease in total emissions; negative values indicate a net increase in total emissions. Observed average annual energy intensity of coal (0.97 tCO2/MWh) and natural gas (0.40 tCO2/MWh) are documented in Table 4.1.

4.6. Conclusion

The impact of new bioenergy production on carbon emissions in Oregon is most influenced by whether or not feedstocks are constrained to logging residues, at least as the scales modeled. The residual-only scenarios yielded the lowest average annual net emissions over the 17-year horizon (Table 4.12), and were less than 1 percent of the same facilities without constrained feedstocks. However, net annual emissions are negligible or even negative for all but scenario #2, suggesting that the scale of modeled production has little impact on statewide GHG profiles. Comparing results to the baseline condition from 2019 to 2035 also suggests that net emissions are more likely a function of changes in national resource conditions and market dynamics than with the operation of bioenergy facilities in Oregon. As reported, changes are projected to have direct effects on landscape forest carbon, but the total GHG implications of changes in energy systems requires that net forest emissions be compared against a reference condition in which fossil fuels or other generation technologies are used. Projected forest emissions were compared to the 10-year in-state coal and natural gas emissions (2006-2015) to illustrate possible carbon offsets by modeled scenario. But comparison to future fossil fuel emissions was beyond the scope of this analysis and remains an important area for further research.

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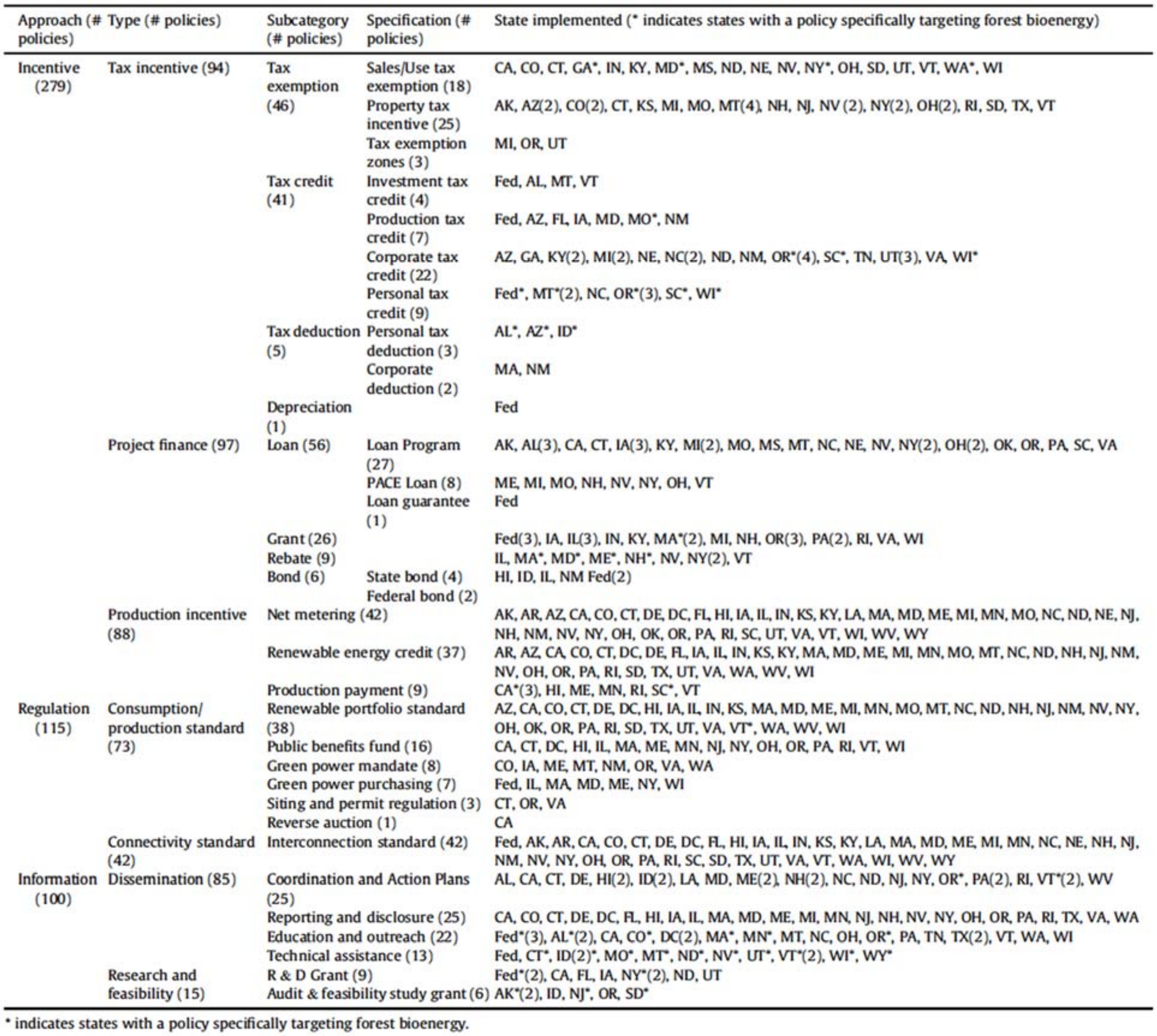
4.8. Appendix A:

Ebers et al. (2016) Classification of State's Policy Approaches for Forest Biomass Production.



Approach (# policies)	Type (# policies)	Subcategory (# policies)	Specification (# policies)	State implemented (* indicates states with a policy specifically targeting forest bioenergy)
Incentive (279)	Tax incentive (94)	Tax exemption (46)	Sales/Use tax exemption (18)	CA, CO, CT, GA*, IN, KY, MD*, MS, ND, NE, NV, NY*, OH, SD, UT, VT, WA*, WI
			Property tax incentive (25)	AK, AZ(2), CO(2), CT, KS, MI, MO, MT(4), NH, NJ, NV (2), NY(2), OH(2), RI, SD, TX, VT
			Tax exemption zones (3)	MI, OR, UT
		Tax credit (41)	Investment tax credit (4)	Fed, AL, MT, VT
			Production tax credit (7)	Fed, AZ, FL, IA, MD, MO*, NM
			Corporate tax credit (22)	AZ, GA, KY(2), MI(2), NE, NC(2), ND, NM, OR*(4), SC*, TN, UT(3), VA, WI*
			Personal tax credit (9)	Fed*, MT*(2), NC, OR*(3), SC*, WI*
		Tax deduction (5)	Personal tax deduction (3)	AL*, AZ*, ID*
			Corporate deduction (2)	MA, NM
		Depreciation (1)		Fed
	Project finance (97)	Loan (56)	Loan Program (27)	AK, AL(3), CA, CT, IA(3), KY, MI(2), MO, MS, MT, NC, NE, NV, NY(2), OH(2), OK, OR, PA, SC, VA
			PACE Loan (8)	ME, MI, MO, NH, NV, NY, OH, VT
			Loan guarantee (1)	Fed
		Grant (26)		Fed(3), IA, IL(3), IN, KY, MA*(2), MI, NH, OR(3), PA(2), RI, VA, WI
		Rebate (9)		IL, MA*, MD*, ME*, NH*, NV, NY(2), VT
		Bond (6)	State bond (4)	HI, ID, IL, NM Fed(2)
			Federal bond (2)	
	Production incentive (88)	Net metering (42)		AK, AR, AZ, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, NC, ND, NE, NJ, NH, NM, NV, NY, OH, OK, OR, PA, RI, SC, UT, VA, VT, WI, WV, WY
		Renewable energy credit (37)		AR, AZ, CA, CO, CT, DC, DE, FL, IA, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, OH, OR, PA, RI, SD, TX, UT, VA, WA, WV, WI
		Production payment (9)		CA*(3), HI, ME, MN, RI, SC*, VT
Regulation (115)	Consumption/ production standard (73)	Renewable portfolio standard (38)		AZ, CA, CO, CT, DE, DC, HI, IA, IL, IN, KS, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, NY, OH, OK, OR, PA, RI, SD, TX, UT, VA, VT*, WA, WV, WI
		Public benefits fund (16)		CA, CT, DC, HI, IL, MA, ME, MN, NJ, NY, OH, OR, PA, RI, VT, WI
		Green power mandate (8)		CO, IA, ME, MT, NM, OR, VA, WA
		Green power purchasing (7)		Fed, IL, MA, MD, ME, NY, WI
		Siting and permit regulation (3)		CT, OR, VA
		Reverse auction (1)		CA
	Connectivity standard (42)	Interconnection standard (42)		Fed, AK, AR, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, NC, NE, NH, NJ, NM, NV, NY, OH, OR, PA, RI, SC, SD, TX, UT, VA, VT, WA, WI, WV, WY
Information (100)	Dissemination (85)	Coordination and Action Plans (25)		AL, CA, CT, DE, HI(2), ID(2), LA, MD, ME(2), NH(2), NC, ND, NJ, NY, OR*, PA(2), RI, VT*(2), WV
		Reporting and disclosure (25)		CA, CO, CT, DE, DC, FL, HI, IA, IL, MA, MD, ME, MI, MN, NJ, NH, NV, NY, OH, OR, PA, RI, TX, VA, WA
		Education and outreach (22)		Fed*(3), AL*(2), CA, CO*, DC(2), MA*, MN*, MT, NC, OH, OR*, PA, TN, TX(2), VT, WA, WI
		Technical assistance (13)		Fed, CT*, ID(2)*, MO*, MT*, ND*, NV*, UT*, VT*(2), WI*, WY*
	Research and feasibility (15)	R & D Grant (9)		Fed*(2), CA, FL, IA, NY*(2), ND, UT
		Audit & feasibility study grant (6)		AK*(2), ID, NJ*, OR, SD*

* indicates states with a policy specifically targeting forest bioenergy.

5. South Carolina

5.1 Executive Summary

The impact of new bioenergy production on carbon emissions in South Carolina is a function of existing energy production and consumption, forest growth and respiration, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to establish the reference baseline condition for South Carolina. Net carbon emissions from adding new electricity generation using forest feedstocks is estimated from 2014 to 2035. These data may be used for establishing criteria for incorporating forest feedstocks into state and national greenhouse gas (GHG) accounting frameworks.

Model Parameters and Inputs

The SubRegional Timber Supply (SRTS) model is a timber market projection system, solving for a recursive product market equilibrium using market parameters derived from econometric studies, forest dynamics based on USDA Forest Service data, and exogenous demand forecasts (e.g., Abt et al. 2009; Prestemon and Abt 2002). It utilizes field inventory and timber product output data from the US Forest Inventory and Analysis (FIA) program to characterize resource conditions and harvest activity. The advantage of this modeling approach is that projections are based on observed harvest-price-inventory relationships within the region, avoiding the need to exogenously establish market behavior (e.g., profit maximization).

The carbon emissions analyzed here are a function of landscape live-tree carbon and power plant emissions from the combustion of biomass for energy generation. Landscape carbon is based on (1) forest growth and respiration (i.e., forest structure is a function of change in age class over time, decay, mortality), (2) removals (e.g., harvests, timber stand improvement and restoration projects), and (3) fire, disturbance (e.g. hurricanes), insects, and diseases infestations. The location of carbon emissions is further influenced by forest products market dynamics driving competition and subsequent feedstock purchasing behavior. This dynamic will affect the location and intensity of forest harvesting, which affects subsequent forest growth and respiration.

In consultation with South Carolina forestry and energy stakeholders, the five scenarios set out below were selected to model net change in forest land use and carbon emissions resulting from using forest feedstocks for electricity generation. SRTS is used to model different levels of forest residual utilization for each scenario (0%, 25%, and 50%). Zero percent harvest residuals assumes all demand is met with harvested roundwood, and 50 percent harvest residuals assume half of facility demand is met with residues with the balance coming from roundwood. Each new facility is assumed to begin operations in 2019 or 2020. All scenarios assume continuation of current softwood/hardwood harvest mix.

South Carolina modeled scenarios.

Scenario	2019	2020	Key Assumptions
South Carolina 1	20 MW		0%, 25%, 50% logging residues
South Carolina 2	20 MW	20 MW	0%, 25%, 50% logging residues
South Carolina 3	2 - 20 MW	20 MW	0%, 25%, 50% logging residues
South Carolina 4	2 - 20 MW	2 - 20 MW	0%, 25%, 50% logging residues
South Carolina 5	4 - 20 MW	4 - 20 WM	0%, 25%, 50% logging residues

Facilities are assumed to use 280,000 green tons/year each, consuming both residues and virgin fiber. Specific locations were not chosen for facilities; new demand was spread evenly throughout the state.

Each facility has an assumed electricity-only heat rate (efficiency) of 27%, and heat content of 8,400 BTU per dry pound of biomass feedstock. The reference case assumes a modified baseline established using year 2011 TPO data and estimates of new forest product demand expected in the state.

We do not assume that forest biomass is carbon neutral. Rather, forest carbon is accounted for in real-time. A net increase in GHG emissions occurs when forest carbon storage in a bioenergy scenario is lower than that of the baseline. Alternatively, a net decrease in GHG emissions occurs when there is more forest carbon stored in the bioenergy scenario than in the baseline. In both bioenergy and baseline scenarios, forest carbon totals are aggregated from live tree, dead tree, understory, down dead, and forest floor pools. Owing to a variety of alternative fates, such as burning slash piles in pine systems to assist in site preparation, the short residence time of residues in hardwood or un-burned systems, or the possibility that residues not used for energy generation will be used for some other application, we assume that residues for energy production have a minimal influence on net forest carbon storage.

Model Scenario Results

SRTS model runs project a decline in inventory and associated price spike for both pine pulpwood and pine small sawtimber, while subtle changes in price and inventory are projected for sawtimber and hardwood pulp. These trends are robust across scenarios, suggesting that trends are a function of larger resource and market dynamics, and have less to do with the operation of bioenergy facilities in South Carolina, at least at the scales considered in Scenarios #1 through #4. However, the addition of bioenergy facilities does have a mixed effect on forest acreage and land use. The addition of new capacity is associated with a small decline in forest area relative to the base case. Plantation pine, natural pine, and upland hardwoods make up a large portion of the net change in acreage.

The modeling framework assumes that land use change is largely driven by changes in the pine sawtimber market. New facility demand combined with demand from existing fiber facilities as part of the baseline, results in substantial price and inventory effects in pine pulpwood, and small pine sawtimber stands. There is minimal change in pine sawtimber, however. As a result, new facilities result in a reduction in forest carbon across scenarios, presumably as harvests and the volume of material extracted increases.

The table below shows power plant and landscape emissions by scenario (tCO_2/yr), and by MWh of electricity production. Scenario #5 yields the largest impact on total emissions, but similar emissions to other scenarios on an MWh basis. Utilization of logging residuals has a different impact on emissions, depending on the number of facilities and total bioenergy demand modeled. In scenarios #1 (20 MW) and #4 (4-20 MW), average annual emissions decline with an increase in residual utilization. In scenario #2 (2-20 MW), emissions increase slightly with an increase in residual utilization. Emissions remain stable in scenario #3 (3-20MW). And in scenario #5 (8-20 MW), annual emissions increase when increasing residual utilization from zero to 25 percent, but declines substantially from 25 percent to 50 percent.

To understand the impact of any scenario, annual emissions from biomass need to be compared to annual emissions from the reference condition using fossil fuels to produce the same amount of energy (189,000 MWh/yr to 1,120,000 MWh/yr). Net change in projected forest carbon emissions were compared to the 10-year average in-state coal and natural gas carbon emissions to illustrate possible offsets by modeled scenario. Actual offsets would require comparison to future fossil fuel emissions. Positive values indicate a net displacement of fossil fuel emissions, or decline in total emissions; negative values indicate a net increase in total emissions as a result of the scenario. Results in Table 5.13 illustrate that total carbon emissions would be less for each biopower scenario when compared to the 10-year average fossil fuel alternative for all but scenario #1 with zero percent residuals utilized (coal: -0.27 t CO2/MWh; natural gas: -0.79 t CO_2/MWh), and scenarios #2 natural gas with 25 percent (-0.15 t CO_2/MWh) and 50 percent residuals utilized (-0.19 t CO_2/MWh). The largest decline in emissions are observed comparing to coal power and where 50% of residuals are utilized for power production.

Average annual net change in landscape forest carbon emissions, 2019-2035.

Scenario (% residues utilized)	Feedstock consumption (bdt/yr)	Power plant emissions (tonnes CO2/yr)	Energy generation (MWh/yr)	South Carolina live tree emissions (tCO2/yr)	South Carolina live tree energy intensity (tCO2/MWh)	Net fossil fuel energy intensity displacement (tCO2/MWh)*	
						Coal	NG
South Carolina 1 (0%)	140,000	256,480	189,000	232,818	1.23	-0.27	-0.79
South Carolina 2 (0%)	280,000	512,960	366,882	144,310	0.39	0.57	0.05
South Carolina 3 (0%)	420,000	769,440	555,882	178,193	0.32	0.64	0.12
South Carolina 4 (0%)	560,000	1,025,920	733,765	255,775	0.35	0.61	0.09
South Carolina 5 (0%)	1,120,000	2,051,840	1,467,529	493,323	0.34	0.62	0.10
South Carolina 1 (25%)	140,000	256,480	189,000	39,521	0.21	0.75	0.23
South Carolina 2 (25%)	280,000	512,960	366,882	215,293	0.59	0.37	-0.15
South Carolina 3 (25%)	420,000	769,440	555,882	180,780	0.33	0.63	0.11
South Carolina 4 (25%)	560,000	1,025,920	733,765	232,413	0.32	0.64	0.12
South Carolina 5 (25%)	1,120,000	2,051,840	1,467,529	626,240	0.43	0.53	0.01
South Carolina 1 (50%)	140,000	256,480	189,000	10,304	0.05	0.91	0.39
South Carolina 2 (50%)	280,000	512,960	366,882	232,638	0.63	0.33	-0.19
South Carolina 3 (50%)	420,000	769,440	555,882	218,413	0.39	0.57	0.05
South Carolina 4 (50%)	560,000	1,025,920	733,765	144,309	0.20	0.76	0.24
South Carolina 5 (50%)	1,120,000	2,051,840	1,467,529	255,774	0.17	0.79	0.27

*Net change in average annual emissions comparing bioenergy scenarios (years 2019-2035) to coal and natural gas (NG) (years 2006-2015). Positive values indicate a net decrease in total emissions; negative values indicate a net increase in total emissions.

Conclusion

The impact of new bioenergy production on carbon emissions in South Carolina is significantly influenced by whether or not logging residues are utilized. But the impact of residuals differs depending on the scale of bioenergy demand modeled over the 17-year horizon. SRTS model runs project a decline in inventory and associated price spike for both pine pulpwood and pine small sawtimber, which are robust across scenarios suggesting that trends are a function of larger resource and market dynamics, and have less to do with the operation of bioenergy facilities in South Carolina. However, the addition of bioenergy facilities does have a mixed effect on forest acreage and land use. The addition of new capacity is associated with a small decline in forest area relative to the base case. As reported, changes are projected to have direct effects on landscape forest carbon, but the total GHG implications of changes in energy systems requires that net forest emissions be compared against a reference condition in which fossil fuels or other generation technologies are used. Projected forest emissions were compared to the 10-year in-state coal and natural gas emissions (2006-2015) to illustrate possible carbon offsets by modeled scenario. But comparison to future fossil fuel emissions was beyond the scope of this analysis and remains an important area for further research.

5.2. Introduction

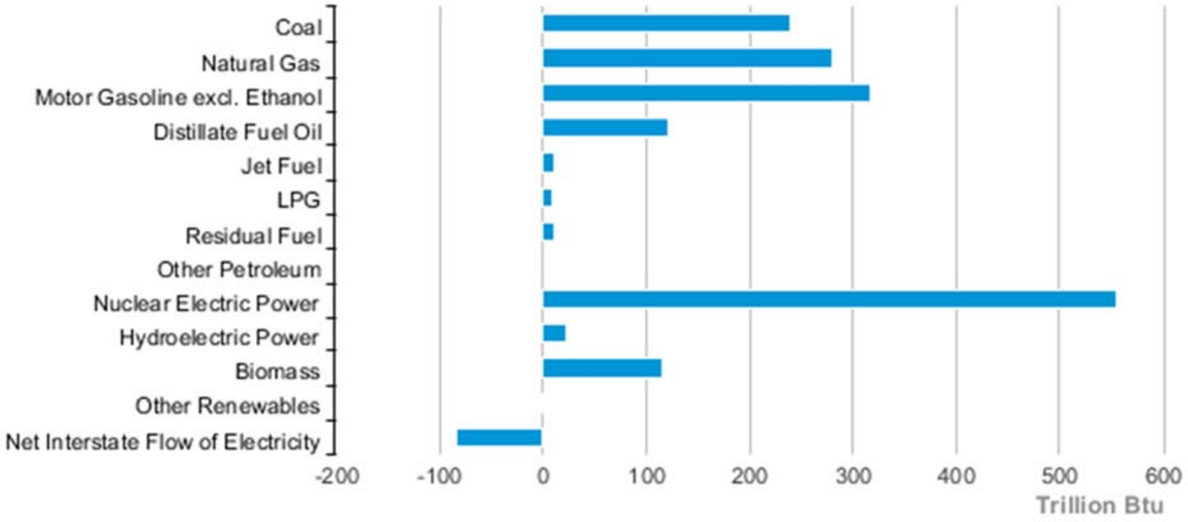
The impact of new bioenergy production on carbon emissions in South Carolina is a function of existing energy production and consumption, forest growth and respiration, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to establish the reference baseline condition for South Carolina. Net carbon emissions from adding new electricity generation using forest feedstocks is estimated from 2014 to 2035. These data may be used for establishing criteria for incorporating forest feedstocks into state and national greenhouse gas (GHG) accounting frameworks.

5.3 South Carolina Energy Profile

5.3.1. Energy Production and Consumption

State energy profiles are comprised of energy production, energy consumption, and energy imports, which are a function of price and availability.[27] In 2015, the most recent year comprehensive US Energy Information Agency (EIA) data are available,[28] South Carolina's primary energy production was limited to nuclear electricity power (555.9 trillion British Thermal Units (Btu)) and renewable energy (120.3 trillion Btu) (EIA 2017a, Table P2), namely hydroelectric power, biomass, and other renewables (EIA 2017a, Table P2; EIA 2017c). The state had no primary production of coal, natural gas, crude oil, or biofuels (EIA 2017a, Table P2). South Carolina consumed 1,648.5 trillion Btu of energy in 2015 (Figure 5.1.), of which 972.2 trillion Btu was produced from imports of primary energy production and their derivatives from other states (EIA 2017a, Table P3). In 2015, using these imports and its own production, the state exported 82.7 trillion Btu in the form of electricity to other states (EIA 2017b, Table C1).

Figure 5.1. South Carolina Energy Consumption Estimates, 2015 (Source: EIA 2017c).



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[27] Since energy prices are fairly volatile, this report does not include price information. Historic (1970-2015) energy price information is available at: https://www.eia.gov/state/seds/sep_prices/notes/pr_print.pdf.

[28] As of October 2017.

5.3.2. Electricity Production and Consumption

In 2015, South Carolina produced 96.5 million megawatt hours (MWh) of electricity (EIA 2016a), which was 97.2 percent less than produced in 2006 (Table 5.1.). The majority of that electricity was produced from nuclear power (55.1%), coal (23.4%), and natural gas (17.1%) (EIA 2016a). Nearly 5 percent of electricity generated within the state was from renewable energy sources, with hydropower providing 2.7 percent, and wood and wood derived fuels 2.2 percent (EIA 2016a). Total annual emissions across all energy sources averaged 0.37 tCO2/MWh. Coal derived energy produced the majority of emissions averaging 0.96 tCO2/MWh per year.

Table 5.1. Electricity Generation and Emissions for South Carolina, by Energy Source* (Source: EIA 2016a).

Year	Coal	Natural Gas	Nuclear	Hydro	Pumped storage***	Wood and Wood Derived Fuels	Total**	CO2 Emissions (Mt CO2)	Energy Intensity (tCO2/MWh)
	Million megawatt hours								
2006	39.5	6.1	50.8	1.8	-1.1	1.8	99.3	41.3	0.42
2007	41.6	6.0	53.2	1.6	-1.2	1.9	103.4	42.6	0.41
2008	41.5	5.7	51.8	1.1	-1.3	1.7	101.0	42.5	0.42
2009	34.5	9.8	52.1	2.3	-1.0	1.6	100.1	38.1	0.38
2010	37.7	10.9	52.0	2.4	-0.9	1.7	104.2	41.4	0.40
2011	34.2	12.9	52.9	1.6	-0.9	2.0	103.0	38.7	0.38
2012	28.4	14.3	51.1	1.4	-0.9	1.9	96.8	34.2	0.35
2013	24.4	11.8	54.3	3.2	-0.8	2.0	95.2	28.8	0.30
2014	28.9	11.4	52.4	2.6	-0.9	2.2	97.2	33.1	0.34
2015	22.6	16.5	53.2	2.6	-0.9	2.1	96.5	29.8	0.31
	Energy intensity (tCO2/MWh)								
10-yr avg	0.96	0.44	0.0	0.0	0.0	0.0	0.37	--	--

* Table omits energy sources that produced an average of 1 million MWh or less per year during these 10 years. This included "Petroleum" (produced an average of 0.2 million MWh per year), "Other Biomass" (averaged: 0.1 million MWh/year), "Other" sources (averaged 0.1 million MWh/year), and "Solar Thermal and Photovoltaic" and "Wind" (both of which averaged less than: 0.1 million MWh/year).

** Row totals may not add up due to rounding and sources omitted in accordance with previous note.

*** Pumped storage is negative because "more electricity is used to force water uphill…than is produced when it flows downhill" (EIA 2013).

South Carolina's electricity and combined heat and power (CHP) generators produced 96.5 million MWh of electricity in 2015. Electricity generators produced the vast majority of this (93.5 million MWh; 96.9% of all generation), of which electric utilities generated 92.4 million MWh and independent power producers generated 1.1 million MWh (EIA 2016a). CHP facilities generated only 3 million MWh of the state's electricity – industrial power CHPs generated 1.7 million MWh and electricity power CHPs generated 1.3 million MWh, while commercial power CHPs generated less than 0.1 million MWh (EIA 2016a).

South Carolina consumed 81.3 million MWh of electricity and exported 15.2 million MWh in 2015 (EIA 2016a; EIA 2016b). The largest shares of electricity used within the state was by the residential (37%) and industrial (36.1%) sectors. The industrial sector consumed 27 percent and the transportation sector consumed only none of this electricity (EIA 2016b).

5.3.3. Electricity from Forest Biomass Resources. In 2015, net electricity generation from forest biomass, using EIA's Wood and Wood Derived Fuel definition,[29] provided more than 2.1 million MWh (2.2%) of South Carolina's electricity (Table 5.2) – nearly as much as hydropower, and more than any other sources besides coal, natural gas, and nuclear (Table 5.1) (EIA 2016a). Forest biomass-based electricity generation increased 16.5 percent from 2006 to 2015, with 66.4 percent of that electricity in 2015 produced by industrial power CHP facilities (EIA 2016a).

Table 5.2. South Carolina Net Generation from "Wood and Wood Derived Fuels" by Type of Producer and Year in thousand megawatt hours (Source: EIA 2016a).

Year	Combined Heat and Power			Electricity Generators		Total
	Industrial Power	Commercial Power	Electricity Power	Independent Power Producers	Electricity Utilities	
2006	1,455.5	0	0	0	348.9	**1,804.4**
2007	1,519.7	0	0	0	375.8	**1,895.4**
2008	1,404.6	0	0	0	291.4	**1,696.1**
2019	1,329.1	0	0	0	281.6	**1,610.7**
2010	1,447.8	0	0	0	294.3	**1,742.1**
2011	1,697.7	0	0	0	290.4	**1,988.1**
2012	1,577.3	0	19.1	0	344.5	**1,941**
2013	1,633.5	0	60.5	7.4	311.6	**2,013**
2014	1,596.4	0	64.6	242.8	339.9	**2,243.7**
2015	1,397.4	0	71.6	318.6	315.4	**2,103**

5.3.4. Biomass Thermal Heat Generation

In 2015, heat from wood, wood-derived fuels, and biomass waste[30] was used in South Carolina's residential, commercial, and industrial sectors (Table 5.3.) (EIA 2017b). EIA estimated that thermal uses (78.5 trillion Btu) of these materials in the state were 4.6 times greater than the 17.5 trillion Btu from the use of this biomass to produce electricity (EIA 2017b, Tables CT3 and CT8),[31] and that South Carolina's thermal use of forest biomass increased 6.9 percent from 2006 to 2015.

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[29] EIA (2017d) defines Wood and Wood-Derived Fuels as "Wood/Wood Waste Solids (including paper pellets, railroad ties, utility poles, wood chips, bark, and wood waste solids)[,] Wood Waste Liquids (excluding Black Liquor but including red liquor, sludge wood, spent sulfite liquor, and other wood-based liquids)[, and] Black Liquor. *Note:* EIA's (2017d) "Other Biomass" category includes other types of biomass, such as "Agricultural By-Products[,] Municipal Solid Waste[,] Other Biomass Gas (including digester gas, methane, and other biomass gases) [,] Other Biomass Liquids[,] Other Biomass Solids[,] Landfill Gas[, and] Sludge Waste. However, since this report's modeling focuses on forest biomass and its derivatives, this report focuses exclusively on EIA's Wood and Wood-Derived Fuels.

[30] EIA (2017d) defines biomass waste as "[o]rganic non-fossil material of biological origin that is a byproduct or a discarded product. Biomass waste includes municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural crop byproducts, straw, and other biomass solids, liquids, and gases; but excludes wood and wood-derived fuels (including black liquor), biofuels feedstock, biodiesel, and fuel ethanol. Note: EIA biomass waste data also include energy crops grown specifically for energy production, which would not normally constitute waste." *Note:* This definition differs from EIA's definition of "Other Biomass" – see previous footnote.

[31] "The electric power sector comprises electricity-only and combined-heat-and-power (CHP) plants ... whose primary business is to sell electricity, or electricity and heat, to the public" (EIA 2017b, 441).

Table 5.3. South Carolina Energy Consumption Estimates for Thermal and Electricity Power from "Wood, Wood-Derived Fuel, and Biomass Waste" by Year and Type of Producer in trillion Btu (Source: EIA 2017b, Tables CT2, CT3, CT4, CT5, CT6, CT8).

Year	Thermal Power (trillion Btu)				Electricity Power (trillion Btu)	Total Consumption (Trillion Btu)
	Residential Sector (thousand cords*)	Commercial Sector	Industrial Sector	Thermal Total		
2006	3.4 (170)	1.9	68.2	73.4	6.9	**80.4**
2007	3.8 (188)	1.8	67.2	72.8	6.4	**79.2**
2008	4.2 (210)	1.8	67.7	73.6	6.8	**80.5**
2009	3.9 (196)	1.4	65.8	71.2	8.5	**79.6**
2010	3.4 (171)	0.5	70	74	8.8	**82.7**
2011	3.5 ((175)	0.5	79.6	83.6	8.9	**92.5**
2012	3.3 (163)	0.5	82.1	85.8	10.7	**96.5**
2013	4.5 (225)	0.5	76.1	81.1	11.7	**92.8**
2014	4.6 (229)	0.5	80.4	85.6	16.1	**101.7**
2015	3.4 (171)	0.6	74.4	78.5	17.1	**95.6**

* EIA only estimated cord wood usage for this sector (EIA 2017b, Table CT4).

5.3.5. State Energy Choices

State energy policy choices are based on local, state, regional, and national goals, such as economic development, energy security, energy reliability (e.g., base and peak load capacity), energy prices, and air pollution emissions, including greenhouse gas emissions. These policies influence states' energy mixes and can cause energy producers and consumers to favor one or more energy sources over others. As Ebers et al. (2016, 67) noted as of "September 2013, federal and state governments had created 494 policies to support production of electricity and heat from forest biomass." Building on Becker et al. (2011), Ebers et al. (2016, 67) developed "a four-tier classification structure to categorize policy instruments based on: approach (incentive, regulation, information), type (e.g. tax incentive), subcategory (e.g. tax exemption), and specification (e.g. sales tax exemption)" (see Appendix A).

In South Carolina, the most common policy approaches focused on stimulating forest biomass energy were corporate and personal tax credits, and production payments.[32] Other incentives specific to renewable energy, but not limited to electricity or heat produced from forest biomass, included net metering, interconnection standards, and a loan program (Ebers et al. 2016).

5.3.6. Biomass Energy CO_2 and Other Emissions

State energy choices regarding fossil fuels and renewables to produce heat and electricity have CO_2 and other emission implications. Emissions from biomass energy generation vary greatly depending on the feedstock source, location, conversion efficiency, and other factors. Combining heat with electricity production significantly increases efficiency over standalone electricity production and reduces GHG emissions per unit of energy generation, while dried forest biomass (e.g., pellets and dried wood chips) will provides higher conversion efficiencies than green wood chips (Schlamadinger et al. 1997). Feedstock proximity, which affects greenhouse gas emissions from biomass transportation also impacts emissions, with biomass facilities price- and volume-constrained based on feedstock availability and competition from other biomass users (Schlamadinger et al. 1997, Galik et al. 2009).

In 2015, electricity production from *all sources* in South Carolina produced an estimated 29.8 million metric tons of CO_2, 26,116 metric tons of SO_2, and 17,589 metric tons of NO_X (EIA 2016c). Of these emissions, wood and wood-derived fuels produced 35.9 percent of the state's SO_2 emissions, and 21.4

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[32] The policy approaches reported in this paragraph use Ebers et al.'s (2016) policy names/terminology.

percent of its NO$_X$ emissions (Table 5.4.) (EIA 2016c). Because the EIA follows current international convention and assumes that CO_2 "released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions" (EIA 2011), *none* of South Carolina's estimated CO_2 electricity emissions include CO_2 emissions from biomass.[33]

Table 5.4. South Carolina Estimated Emission from "Wood and Wood-Derived Fuel" by Type of Producer in metric tons (Source: EIA 2016c).

Year	Emission	Electric Utility	Independent Power Producers		Commercial		Industrial		Total
			Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	
2006	SO_2	0	0	0	0	0	0	7,359	**7,359**
	NO$_x$	210	0	0	0	0	0	1,579	**1,789**
2007	SO_2	0	0	0	0	0	0	6,939	**6,939**
	NO$_x$	183	0	0	0	0	0	1,564	**1.747**
2008	SO_2	0	0	0	0	0	0	3,617	**3,617**
	NO$_x$	211	0	0	0	0	0	993	**1,2043**
2009	SO_2	3	0	0	0	0	0	6,822	**6,825**
	NO$_x$	209	0	0	0	0	0	1,518	**1,727**
2010	SO_2	4	0	0	0	0	0	8,660	**8,664**
	NO$_x$	177	0	0	0	0	0	1,1675	**1,852**
2011	SO_2	4	0	0	0	0	0	12,040	**12,044**
	NO$_x$	180	0	0	0	0	0	2,558	**2,738**
2012	SO_2	67	15	0	0	0	0	9,862	**9,944**
	NO$_x$	176	135	0	0	0	0	2,031	**2,342**
2103	SO_2	64	1	32	0	0	0	9,244	**9,341**
	NO$_x$	153	14	92	0	0	0	2,479	**2,479**
2014	SO_2	3	54	0	0	0	0	10,177	**10,234**
	NO$_x$	181	52	94	0	0	0	2,793	**3,120**
2015	SO_2	64	69	35	0	0	0	9,197	**9,365**
	NO$_x$	2	66	101	0	0	0	3,586	**3,755**

While international convention and the EIA assume that "the CO_2 released from biofuel or bioenergy combustion … [is] fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy," (EIA 2011, 60) from a landscape perspective forests can be a CO_2 sink, CO_2 source, or carbon neutral (Malmsheimer et al. 2008). Forests are a CO_2 sink when live and dead vegetation, litter, and soil sequester more carbon than emitted, and forests are a carbon source when these emissions exceed sequestration rates (Wear and Coulston 2015). Management actions such as timber harvesting, or natural disturbances like wildfires affecting the CO_2 balance determines the extent to which a forest is a net sink or source of CO_2 to the atmosphere (Woodall et al. 2015). Carbon is also sequestered in harvested wood products, such as lumber and paper, which affects the CO_2 balance (EIA 2011; Malmsheimer et al. 2008). At the end of a products' useful life, the carbon is either released

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[33] As EIA notes, "According to current international convention, CO_2 released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions. The related fossil fuel emissions from the transportation and processing of the biological feedstocks are captured within overall energy sector emissions, but currently they are not allocated to the biofuels. Additionally, the CO_2 released from biofuel or bioenergy combustion is assumed to be fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy. However, analysts have debated whether the increased use of biomass energy may result in a loss of terrestrial carbon stocks and foregone future sequestration by natural vegetation. The initial loss of carbon stocks in natural vegetation cleared to grow biomass feedstocks and the foregone future removal of CO_2 are not captured in energy sector emissions. To capture the potential net emissions, the international convention for GHG inventories is to report the net carbon flux from land use change (such as when forests are converted to cropland to grow feedstocks) in the Land Use category. Although accounting for land use emissions is more challenging than for most of the other emissions sources, emissions and sequestration associated with domestic U.S. land use change should in principle be accounted for in this chapter of the inventory report. However, from a global greenhouse gas emissions perspective, the key uncertainty regarding aggregate net biogenic emissions is indirect land use change that occurs abroad." (EIA 2011).

directly into the atmosphere through burning and energy combustion (Malmsheimer et al. 2011; Miner et al. 2014), or natural decomposition or decay in landfills (Skog 2008).[34]

While most forest-based carbon is eventually released into the atmosphere, forest products and forest biomass energy provide documented benefits. As Malmsheimer et al. (2011, S9) described, "[f]orest products used in place of energy intensive materials such as metals, concrete and plastics (a) reduce carbon emissions (because forest products require less fossil fuel-based energy to produce), (b) store carbon (for a length of time based on products' use and disposal), and (c) provide biomass residuals (i.e., waste wood) that can be substituted for fossil fuels to produce energy. [In addition,] [f]ossil fuel–produced energy releases carbon into the atmosphere that has resided in the Earth for millions of years; forest biomass–based energy uses far less of the carbon stored in the Earth thereby reducing the flow of fossil fuel–based carbon emissions to the atmosphere."

5.4. Forest Sector Profile

5.4.1. The Condition of the Forest Resource

As a lower value commodity relative to sawlogs and other forest products, the availability of biomass for energy generation often depends on traditional forest products markets to generate sufficient financial incentive to enable biomass removal (Oswalt et al. 2018; Miner et al. 2014). These markets depend in large part on the condition of a state's forest resource, species composition, and forest products manufacturing base.

Nearly two-thirds of South Carolina is forested, and the number of acres has changed little since 2011 (Table 5.5.) (Oswalt et al. 2014; 2018). Almost 75 percent of the state's timberlands – forests producing or capable of producing industrial wood, and not withdrawn from timber utilization – have natural origins, as opposed to being planted (Oswalt et al. 2018).

Table 5.5. South Carolina Land Area, by Year, in thousands of acres (Sources: Oswalt et al. 2014; 2018 (Tables 1a)).

Year	Total Land Area	Forestland*					Woodland****	Other Land
		Total	Timberland**		Reserved***	Other		
			Planted	Natural Origin				
2011	19,239	13,120	3,381	9,645	69	26	0	6,119
2017	19,239	12,931	3,258	9,499	159	16	0	6,307

* Forestland is defined as, "Land at least 120 feet (37 meters) wide and at least 1 acre (0.4 hectares) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. The definition here includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest land also includes transition zones, such as areas between forest and nonforest lands that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (37 meters) wide or an acre in size. Forest land does not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

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[34] As Malmsheimer et al. (2011, S30), noted "Of the wood products that enter solid waste disposal sites, more than three quarters of the carbon in solid wood and almost one-half of the carbon in paper is never released to the atmosphere … . The carbon that is released during decay takes many years to reach the atmosphere. For example, the 23% of the solid wood that does decay has a half-life of 29 years. Skog (2008) found that when paper is landfilled, the nonlignin component (56%) decays, leaving the lignin component (44%) as a long-term store in the landfill … . This nondegradable fraction varies by grade, from approximately 10% for bleached chemical pulp fibers to 85% for mechanical pulp fibers (US EPA 2006)."

** Timberland is defined as, "Forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. (Note: Areas qualifying as timberland are capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.)" (U.S. Forest Service 2017a).

*** Woodland is defined as, "a class of land which consists predominantly of stands of sparse woodland species such as juniper, pinyon juniper, mesquite and small stature hardwood species and are found in the arid to semiarid regions of the interior western United States. These areas must span more than 1 acre (0.4 hectares, have sparse trees capable of achieving 16.4 feet (5 meters) in height in situ, and a tree canopy cover of 5 to 10 percent. When combined with shrubs and bushes these areas may achieve overall cover greater than 10 percent woody vegetation. Trees are defined as woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. These areas do not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

**** Reserved Forestland is defined as, "Land permanently reserved from wood products utilization through statute or administrative designation. Examples include National Forest wilderness areas and National Parks and Monuments." (U.S. Forest Service 2017a).

Softwoods constitute 57.3 percent of South Carolina's timberlands growing stock (Table 5.6.) (Oswalt et al. 2018). Most (71.1%) of the state's estimated 663 million dry tons of above ground biomass is in the boles of live trees with a diameter at breast height of 5 or more inches, 15% in the tops and limbs and 4.4% in stumps (Oswalt et al. 2018). Saplings contain 8.8% of above ground biomass and sound dead biomass, which the U.S. Forest Service defines as salvageable dead trees, comprises 0.6% of all such biomass in the state (U.S. Forest Service 2017a).

Table 5.6. South Carolina Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 (Source: Oswalt et al. 2018 (Tables 17 and 38a)).

Growing Stock Volume *(in million cubic feet)*			**Above Ground Biomass** *(in million dry tons)*						
			Total Biomass	**Live Tree Biomass**					**Sound Dead Biomass**
				Greater than 5-inches DBH			**Sapling Biomass**	**Woodland Species**	
Total	**Softwood**	**Hardwood**		**Boles**	**Stumps**	**Tops/Limbs**			
21,669	12,415	9,254	633	450	28	95	56	0	4

Data may not add to totals because of rounding.

In 2017, net growth exceeded mortality and removals in South Carolina timberland by nearly 1.2 billion cubic feet (Table 5.7.), and net growth increased 3.4 percent from 2011 to 2017 (Oswalt et al. 2014; 2018). More than 76 percent of net growth in 2017 occurred in softwoods (Table 5.7.).

Table 5.7. South Carolina Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in thousand cubic feet (Source: Oswalt et al. 2014; 2018 (Table 36)).

	All Species			**Softwoods**			**Hardwoods**		
	Net growth*	**Removals**	**Mortality**	**Net growth***	**Removals**	**Mortality**	**Net growth***	**Removals**	**Mortality**
2011	1,157,784	708,355	131,180	853,561	525,010	72,663	304,224	183,346	58,517
2017	1,197,025	658,973	136,424	911,013	553,013	72,070	286,012	105,958	64,354

* "[N]et annual growth [is t]he average annual net increase in the volume of trees during the period between inventories. Components include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year and minus the net volume of trees that became cull trees during the year" (Oswalt 2014, 33). Thus, net annual growth includes mortality, but does not include removals, so removals must be subtracted from net growth to calculate increases or decreases in growing stock *in the forest*.

Non-industrial owners, also known as family forest owners, own 55.3 percent of South Carolina's timberlands and industrial landowners own 32.2 percent (Table 5.8) (Oswalt et al. 2018). The federal government administering 8.1 percent of all timberlands, the State of South Carolina 3.1 percent, and counties and municipalities 1.2 percent.

Table 5.8. South Carolina Timberland Area by Ownership, 2017, in thousands of acres (Source: Oswalt et al 2018 (Table 2)).

	Public					**Private**		**Total**
	Federal			**State**	**County & Municipal**	**Industrial**	**Non-Industrial**	
	National Forest	**BLM**	**Other**					
	614	0	433	406	159	4,170	7,149	
Subtotals	1,047							
Totals	1,612					11,319		12,931

Data may not add to totals because of rounding.

5.4.2. The Forest Industry

Nearly 80 percent of timber products manufactured in South Carolina were produced from softwoods (Table 5.9.) (Source: Oswalt et al. 2014 (Table 39)). Private non-industrial forests (e.g., family forest owners) supplied the majority of softwood-based (69%) and hardwood-based (88.4%) feedstocks.

Pulpwood represented 56.6 percent (by volume) of all of the state's timber products. Saw logs (24.9%) were the only other product category using more than 10 percent of in-state wood supply.

Table 5.9. South Carolina Volume of Industrial Timber Products by Ownership Class and Timber Product, 2014, in millions of cubic feet (Source: Oswalt et al. 2014 (Table 39); Forest Service 2017b).

Ownership Class	**Total**	**Saw Logs**	**Veneer Logs**	**Pulpwood**	**Composite Products**	**Residential Fuelwood***	**Post-Poles-Pilings**	**Other Industrial**
Softwoods								
National Forests	14,153	8,379	1,083	3,521	964	65	102	21
Other Public	32,573	9,242	1,361	17,774	2,981	250	236	731
Forest Industry	106,656	37,752	1,322	59,726	4,611	817	816	1,611
Other Private	327,934	84,908	20,183	184,052	26,155	2,513	3,331	6,793
Softwoods Total	475,542	134,525	23,948	265,073	34,712	3,645	4,484	9,155
Hardwoods								
National Forests	0	0	0	0	0	0	0	0
Other Public	4,847	686	115	2,831	0	1,173	0	42
Forest Industry	9,306	485	245	6,240	0	2,251	0	85
Other Private	107,566	13,167	3,417	63,929	0	26,021	0	1,033
Hardwoods Total	121,719	14,337	3,777	73,000	0	29,445	0	1,160
Total Softwoods and Hardwoods	597,261	148,862	27,725	338,073	34,712	33,090	4,484	10,315

Numbers in rows and columns may not add to totals due to rounding.

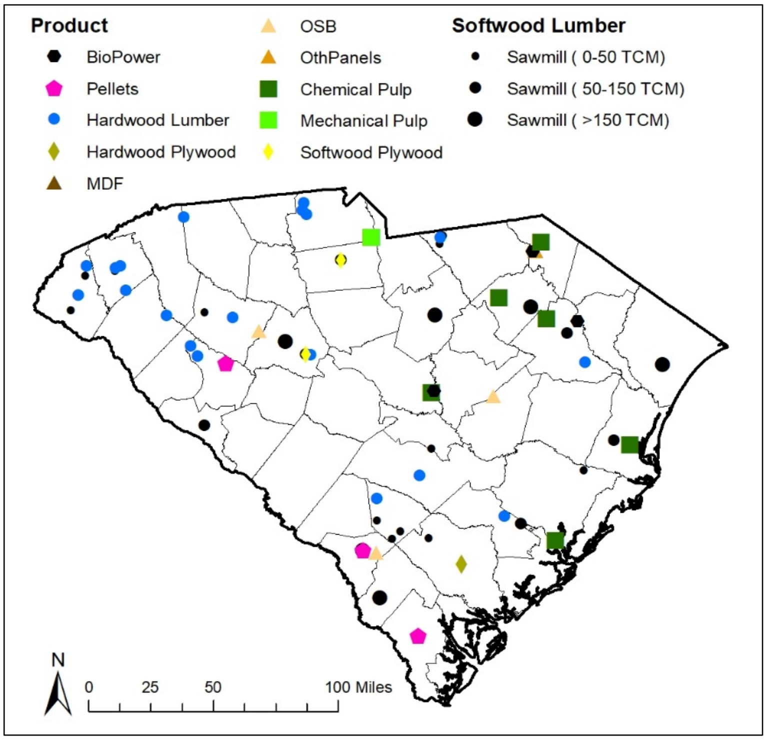
* Residential Fuelwood is consumed for private use (U.S. Department of Energy estimates). Industrial fuelwood included in Other Industrial.

5.5. Forest CO_2 Modeling

5.5.1. Model Parameters and Inputs

The SubRegional Timber Supply (SRTS) model is a timber market projection system, solving for a recursive product market equilibrium using market parameters derived from econometric studies, forest dynamics based on USDA Forest Service data, and exogenous demand forecasts (e.g., Abt et al. 2009; Prestemon and Abt 2002). It utilizes field inventory and timber product output data from the US Forest Inventory and Analysis (FIA) program to characterize resource conditions and harvest activity. The advantage of this modeling approach is that projections are based on observed harvest-price-inventory relationships within the region, avoiding the need to exogenously establish market behavior (e.g., profit maximization). A map of the distribution of South Carolina's forest products facilities is presented in Figure 5.2.

Figure 5.2. South Carolina Primary Wood-Using Mills, by Region, 2014 (Source: Latta et al. 2018).



The modeling parameters for each scenario are based on documented harvest activity derived from TPO data and projected changes in forest product demand provided by partners in South Carolina (Table 5.10). To align the baseline projection to estimates of new facility demand, baseline pine pulpwood demand is assumed to increase by 3.5% per year. We also assumed that 67% of chip-n-saw is used to meet pulpwood demand. These assumptions yield a baseline projection that aligns closely (within 1%) with the cumulative numbers provided by state partners. After 2018, demand is held constant for all remaining years in a scenario.

Harvests are assumed to come from forests identified as timberland by the USDA Forest Service FIA system. Using FIA-derived ecosystem-level equations (Foley et al. 2009, as based on Smith and Heath 2002, and Smith et al. 2006), SRTS forest inventory projections are converted into estimates of on-site forest carbon for each of the five management types by age class included in the model. Model projections focus on the state-level implications of a change in bioenergy demand; results show the implications of forest harvest change in South Carolina only. It is possible that the demand from new facilities in South Carolina could be met with feedstock harvested in neighboring states. It is equally possible, that harvests within South Carolina are feeding markets in other states. Limiting the model run to South Carolina thus provides a reasonable indication of the changes in harvest dynamics and forest land use associated with new bioenergy demand given the composition of existing demand across product categories (Table 5.11). SRTS is most appropriately used to project near-term dynamics, so estimates are only provided for the first 20 years (2015-2035) of alternative bioenergy scenarios.

Table 5.10. Estimate of additional demand (U.S. green tons) by product class (Source: T. Adams, South Carolina Forestry Commission, pers. comm., January 9, 2017).

	----- Pulpwood -----		----- Sawtimber -----	
Year	**Pine**	**Hardwood**	**Pine**	**Hardwood**
2012	125,000	125,000	0	0
2013	600,000	0	0	0
2014	460,000	0	0	100,000
2015	150,000	0	0	0
2016	0	0	300,000	0
2017	1,000,000	0	0	0
2018	1,000,000	0	0	0

Table 5.11. Total number of wood using facilities, production capacity, and demand for wood products in South Carolina, 2014 (Source: Latta et al. 2018 (Table 39)).

Forest Product		**Facilities**	**Capacity**	**Foreign trade***	
				Exports	**Imports**
		---- # ----	*----- million m^3 -----*	*---- million dollars ----*	
Sawlogs	softwood			0	650
	hardwood			0	371
Pulp logs	softwood			14,646	0
	hardwood			1,830	0
Lumber	softwood	561	64,778	4,313	19,212
	hardwood	290	21,895	3,451	837
Plywood	softwood	57	9,005	655	2,420
	hardwood	29	3,634		
Oriented strand board (OSB)		39	20,017	564	4,446
Hardboard		19	709	218	0
Insulation board		49	6,188	284	0
Medium-density fibreboard (MDF)		15	3,596	535	1,841
			-- million tonnes (Mt) --		
Pulp	chemical	116	56,357	6,758	5,064
	mechanical	20	1,912	29	39
Newsprint		11	2,730	800	2,116
Print and writing paper		82	17,861	2,322	4,922
Paperboard		189	59,197	8,414	2,321
Tissue		67	8,260	152	298
Wood pellets		139	6,124	2,909	152
Chips	softwood			4,780	60
	hardwood			843	26
			------ MWh ------		
Forest biopower		152	1,235		
Forest co-firing		530	124		
Recycled pulp				18,883	811

*Port-level foreign trade data is 2010-2014 average from the United States International Trade Commission (USITC) Interactive Tariff and Trade Database (DataWeb), http://DataWeb.usitc.gov.

5.5.2. South Carolina Model Scenarios

The carbon emissions analyzed here are a function of landscape live-tree carbon and power plant emissions from the combustion of biomass for energy generation. Landscape carbon is based on (1) forest growth and respiration (i.e., forest structure is a function of change in age class over time, decay, mortality), (2) removals (e.g., harvests, timber stand improvement and restoration projects), and (3) fire, disturbance (e.g. hurricanes), insects, and diseases infestations. The location of carbon emissions is further influenced by forest products market dynamics driving competition and subsequent feedstock purchasing behavior. This dynamic will affect the location and intensity of forest harvesting, which affects subsequent forest growth and respiration. Total emissions are thus a function of the following variables, which form the basis for the scenarios modeled in South Carolina:

- Facility size and location – influences where the feedstock is procured, distance traveled, and price paid. The number and size of competing forest products industries within a procurement zone subsequently influences price and the distribution of feedstock by end product.
- Number of facilities – affects the distribution of feedstock demand, distance traveled, and associated emissions.

- Feedstock availability – function of land ownership, tree characteristics (species, size, age, and location), and projected growth and yield. Factors such as insect and fire mortality, or policy regulations will affect average annual harvest levels and availability by ownership.
- Feedstock type – the carbon emissions profile is influenced by the type of feedstock used for energy production. For instance, the ratio of clear-cutting to harvest thinnings, or the ratio of pulpwood to logging residuals influences carbon flux.
- Product demand – total wood products demand for the United States is assumed unchanged when adding bioenergy capacity. Total exports also remain static but the distribution of port activity and regional production changes with any new bioenergy.
- Conversion technology – changing the type of biopower facility and rated efficiency will affect the volume of feedstock needed to produce energy, which affects emissions. The type of offset fossil fuel (e.g., coal-fired power) and corresponding conversation efficiency is important.

In consultation with South Carolina forestry and energy stakeholders, five scenarios (Table 5.12) were selected to model net change in forest land use and carbon emissions resulting from using forest feedstocks for electricity generation. SRTS is used to model different levels of forest residual utilization for each scenario (0%, 25%, and 50%). Zero percent harvest residuals assumes all demand is met with harvested roundwood, and 50 percent harvest residuals assume half of facility demand is met with residues with the balance coming from roundwood. Each new facility is assumed to begin operations in 2019 or 2020. All scenarios assume continuation of current softwood/hardwood harvest mix.

Table 5.12. South Carolina modeled scenarios.

Scenario	2019	2020	Key Assumptions
South Carolina 1	20 MW		0%, 25%, 50% logging residues
South Carolina 2	20 MW	20 MW	0%, 25%, 50% logging residues
South Carolina 3	2 - 20 MW	20 MW	0%, 25%, 50% logging residues
South Carolina 4	2 - 20 MW	2 - 20 MW	0%, 25%, 50% logging residues
South Carolina 5	4 - 20 MW	4 - 20 WM	0%, 25%, 50% logging residues

The modeling escalates biopower production with each scenario, starting with one 20 MW facility ranging up to eight new 20 MW facilities; scenario #5 is less plausible from an energy market perspective in South Carolina, but provides insight into how forest markets respond to large demand shocks. Facilities are assumed to use 280,000 green tons/year each, consuming both residues and virgin fiber. Specific locations were not chosen for facilities; new demand was spread evenly throughout the state. Each facility has an assumed electricity-only heat rate (efficiency) of 27%, and heat content of 8,400 BTU per dry pound of biomass feedstock. The reference case assumes a modified baseline established using year 2011 TPO data and estimates of new forest product demand expected in the state (Table 5.10).

We do not assume that forest biomass is carbon neutral. Rather, forest carbon is accounted for in real-time. A net increase in GHG emissions occurs when forest carbon storage in a bioenergy scenario is lower than that of the baseline. Alternatively, a net decrease in GHG emissions occurs when there is more forest carbon stored in the bioenergy scenario than in the baseline. In both bioenergy and baseline scenarios, forest carbon totals are aggregated from live tree, dead tree, understory, down dead, and forest floor pools. Owing to a variety of alternative fates, such as burning slash piles in pine systems to assist in site preparation, the short residence time of residues in hardwood or un-burned systems, or the possibility that residues not used for energy generation will be used for some other application, we assume that residues for energy production have a minimal influence on net forest carbon storage.

The GHG consequences of displacing fossil fuel facilities is assessed for each scenario using the estimated biopower Btu output to calculate GHG emissions associated with an equivalent amount of power from natural gas-fired facilities. Natural gas emissions are calculated at a factor of 117 pounds CO_2 per MMBtu (EIA 2017e), and an operating efficiency for electricity-only applications of 41%. To assess the implications of adding new biomass thermal to displace existing heat from either natural gas or coal, we assume combined heat and electricity efficiencies of 80% for all fuel sources, and an emissions factor for subbituminous coal of 214.3 pounds CO_2 per MMBtu (EIA 2017e). Emissions from alternative fossil fuels are added to the net emissions estimate for each scenario to approximate the relative GHG effect of adding biomass heat or power.

5.5.3. South Carolina Model Scenario Results

Price, inventory, and removal indices for a subset of bioenergy scenarios are shown in Figures 5.3 and 5.4. Each figure shows changes in the price, inventory, and removals for a particular forest product, indexed to the first year of the scenario to show relative change over time. SRTS model runs project a decline in inventory and associated price spike for both pine pulpwood and pine small sawtimber, while subtle changes in price and inventory are projected for sawtimber and hardwood pulp. These trends are robust across scenarios, and between scenarios and baseline runs, suggesting that observed trends are a function of larger resource and market dynamics, and have less to do with the operation of bioenergy facilities in South Carolina, at least at the scales considered in Scenarios #1 through #4. However, the addition of bioenergy facilities does have a mixed effect on forest acreage and land use. The addition of new capacity is associated with a small decline in forest area relative to the base case. Plantation pine, natural pine, and upland hardwoods make up a large portion of the net change in acreage.

Across all scenarios, the addition of facilities results in a reduction in forest carbon, presumably as harvests and the volume of material extracted increases. Including the emissions associated with displaced fossil fuel electricity generation would illustrate the net GHG benefit, which varies both over time and by scenario. To assess thermal applications for the same model runs, we assumed that new facilities could be augmented to also provide heat, which is assumed to replace existing fossil heat either in the form of natural gas or coal. Owing to the increased efficiencies associated with generating usable heat and power, thermal applications suggest a potential to increase the net GHG benefit of new additions to bioenergy capacity.

The modeling framework assumes that land use change is largely driven by changes in the pine sawtimber market. As shown in Figures 5.3 and 5.4, new facility demand combined with demand from existing fiber facilities as part of the baseline (Table 5.10), results in substantial price and inventory effects in pine pulpwood, and small pine sawtimber stands. There is minimal change in pine sawtimber, however. This suggests that there are few new plantations, reduced losses of existing forests, or other land use changes available to offset additional harvest activity, which exhibits downward pressure on net carbon stocks.[35] These trends are exacerbated by the present resource situation South Carolina where constrained feedstock supply contributes to large price swings in certain product classes. Hence, new facilities result in a reduction in forest carbon across scenarios, presumably as harvests and the volume of material extracted increases (Figure 5.5).

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[35] Change in cumulative carbon stock is calculated as the difference in the scenario carbon stock in a given year to the baseline carbon stocks in the same year.

Figure 5.3. Price, inventory, and removal indices for multiple forest products, assuming the addition of one (1) 20MW facility with 50% residue recovery.

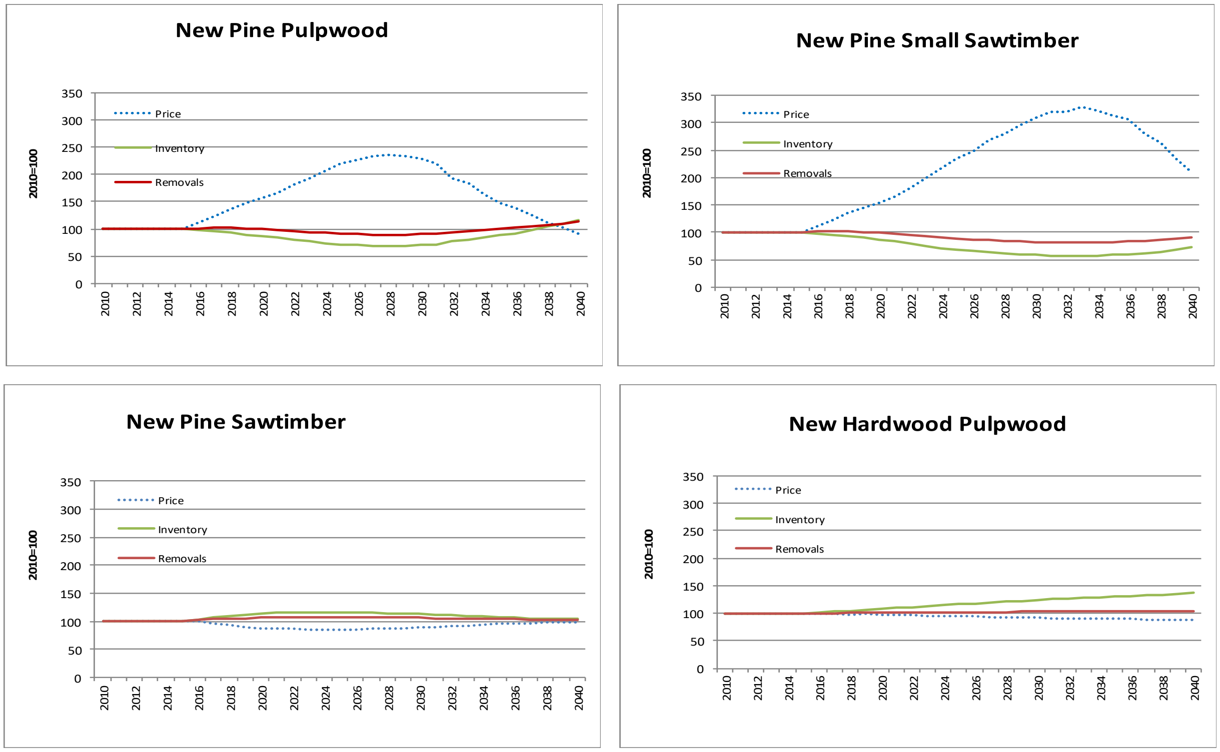
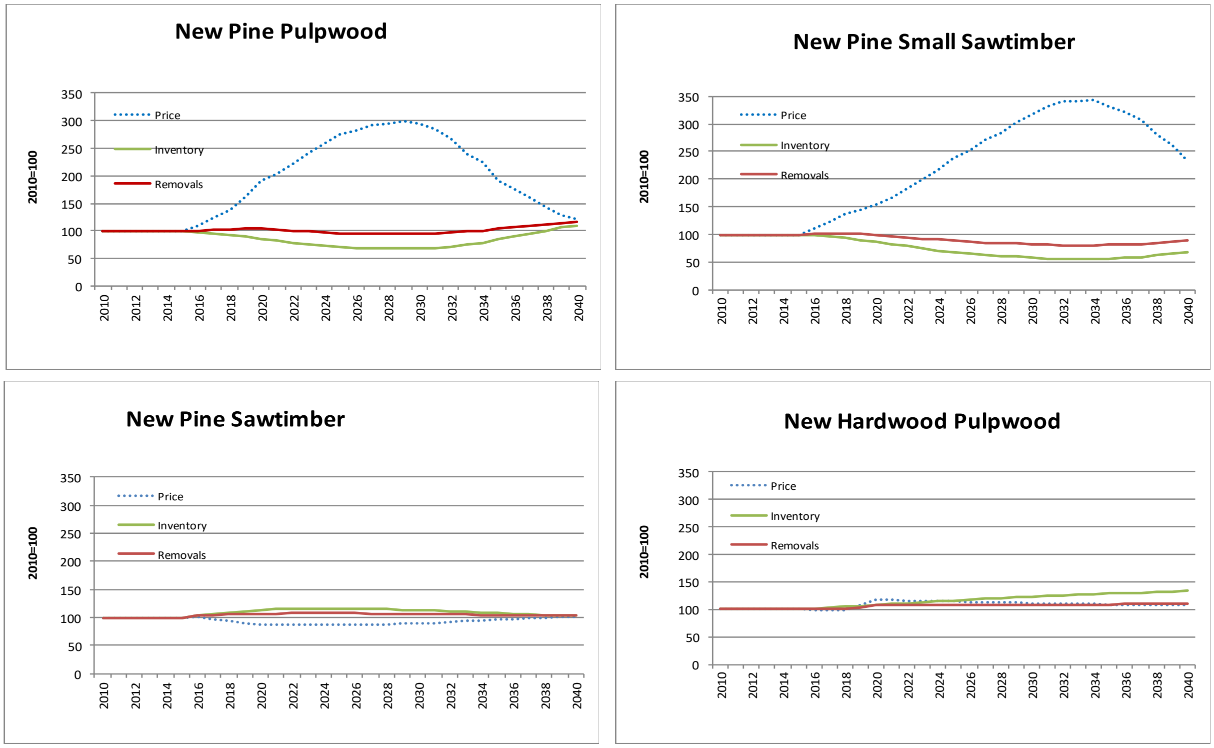
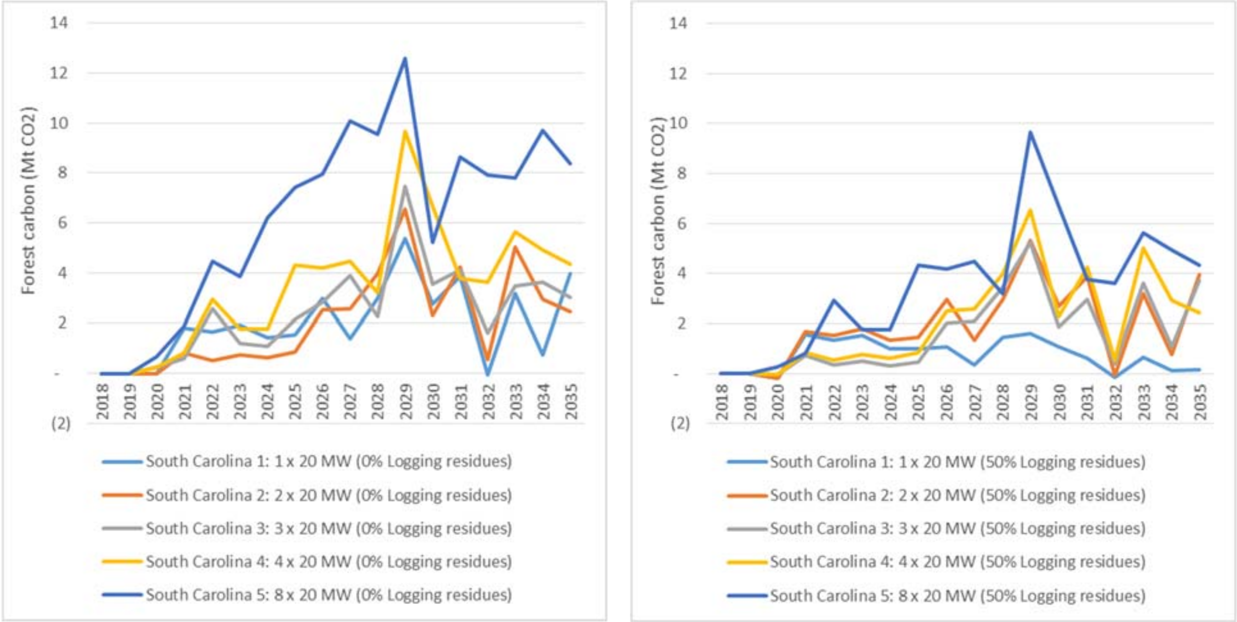


Figure 5.4. Price, inventory, and removal indices for multiple forest products, assuming the addition of eight (8) 20MW facilities with 0% residue recovery.



Annualizing net emissions obscures year-over-year variation, but allows for quick comparison across scenarios. Table 5.13 shows power plant and terrestrial emissions by scenario (tCO_2/yr), and by MWh of electricity production. Scenario #5 yields the largest impact on total emissions, but similar emissions to other scenarios on an MWh basis. Utilization of logging residuals has a different impact on emissions, depending on the number of facilities and total bioenergy demand modeled. In scenarios #1 (20 MW) and #4 (4-20 MW), average annual emissions decline with an increase in residual utilization. In scenario #2 (2-20 MW), emissions increase slightly with an increase in residual utilization. Emissions remain stable in scenario #3 (3-20MW). And in scenario #5 (8-20 MW), average annual emissions increase when increasing residual utilization from zero to 25 percent, but declines substantially from 25 percent to 50 percent.

Figure 5.5. Cumulative carbon stock change from baseline for South Carolina scenarios, 2018 – 2035. The figure on the left represents zero residue utilization, the figure on the right 50%.



To understand the impact of any scenario, annual emissions from biomass need to be compared to annual emissions from the reference condition using fossil fuels to produce the same amount of energy (189,000 MWh/yr to 1,120,000 MWh/yr). Net change in projected forest carbon emissions were compared to the 10-year average in-state coal and natural gas carbon emissions (Table 5.1) to illustrate possible offsets by modeled scenario. Actual offsets would require comparison to future fossil fuel emissions. Positive values indicate a net displacement of fossil fuel emissions, or decline in total emissions; negative values indicate a net increase in total emissions as a result of the scenario. Results in Table 5.13 illustrate that total carbon emissions would be less for each biopower scenario when compared to the 10-year average fossil fuel alternative for all but scenario #1 with zero percent residuals utilized (coal: -0.27 t CO2/MWh; natural gas: -0.79 t CO_2/MWh), and scenarios #2 natural gas with 25 percent (-0.15 t CO_2/MWh) and 50 percent residuals utilized (-0.19 t CO_2/MWh). The largest decline in emissions are observed comparing to coal power and where 50% of residuals are utilized for power production.

Table 5.13. Average annual net change in landscape forest carbon emissions, 2019-2035.

Scenario (% residues utilized)	**Feedstock consumption (bdt/yr)**	**Power plant emissions (tonnes CO2/yr)**	**Energy generation (MWh/yr)**	**South Carolina live tree emissions (tCO2/yr)**	**South Carolina live tree energy intensity (tCO2/MWh)**	**Net fossil fuel energy intensity displacement (tCO2/MWh)***	
						Coal	**NG**
South Carolina 1 (0%)	140,000	256,480	189,000	232,818	1.23	-0.27	-0.79
South Carolina 2 (0%)	280,000	512,960	366,882	144,310	0.39	0.57	0.05
South Carolina 3 (0%)	420,000	769,440	555,882	178,193	0.32	0.64	0.12
South Carolina 4 (0%)	560,000	1,025,920	733,765	255,775	0.35	0.61	0.09
South Carolina 5 (0%)	1,120,000	2,051,840	1,467,529	493,323	0.34	0.62	0.10
South Carolina 1 (25%)	140,000	256,480	189,000	39,521	0.21	0.75	0.23
South Carolina 2 (25%)	280,000	512,960	366,882	215,293	0.59	0.37	-0.15
South Carolina 3 (25%)	420,000	769,440	555,882	180,780	0.33	0.63	0.11
South Carolina 4 (25%)	560,000	1,025,920	733,765	232,413	0.32	0.64	0.12
South Carolina 5 (25%)	1,120,000	2,051,840	1,467,529	626,240	0.43	0.53	0.01
South Carolina 1 (50%)	140,000	256,480	189,000	10,304	0.05	0.91	0.39
South Carolina 2 (50%)	280,000	512,960	366,882	232,638	0.63	0.33	-0.19
South Carolina 3 (50%)	420,000	769,440	555,882	218,413	0.39	0.57	0.05
South Carolina 4 (50%)	560,000	1,025,920	733,765	144,309	0.20	0.76	0.24
South Carolina 5 (50%)	1,120,000	2,051,840	1,467,529	255,774	0.17	0.79	0.27

*Net change in average annual emissions comparing bioenergy scenarios (years 2019-2035) to coal and natural gas (NG) (years 2006-2015). Positive values indicate a net decrease in total emissions; negative values indicate a net increase in total emissions. Observed average annual energy intensity of coal (0.96 tCO2/MWh) and natural gas (0.44 tCO2/MWh) are documented in Table 5.1.

5.6. Conclusion

The impact of new bioenergy production on carbon emissions in South Carolina is significantly influenced by whether or not logging residues are utilized. But the impact of residuals differs depending on the scale of bioenergy demand modeled over the 17-year horizon (Table 5.13). SRTS model runs project a decline in inventory and associated price spike for both pine pulpwood and pine small sawtimber, which are robust across scenarios suggesting that trends are a function of larger resource and market dynamics, and have less to do with the operation of bioenergy facilities in South Carolina. However, the addition of bioenergy facilities does have a mixed effect on forest acreage and land use. The addition of new capacity is associated with a small decline in forest area relative to the base case. As reported, changes are projected to have direct effects on landscape forest carbon, but the total GHG implications of changes in energy systems requires that net forest emissions be compared against a reference condition in which fossil fuels or other generation technologies are used. Projected forest emissions were compared to the 10-year in-state coal and natural gas emissions (2006-2015) to illustrate possible carbon offsets by modeled scenario. But comparison to future fossil fuel emissions was beyond the scope of this analysis and remains an important area for further research.

5.7. References

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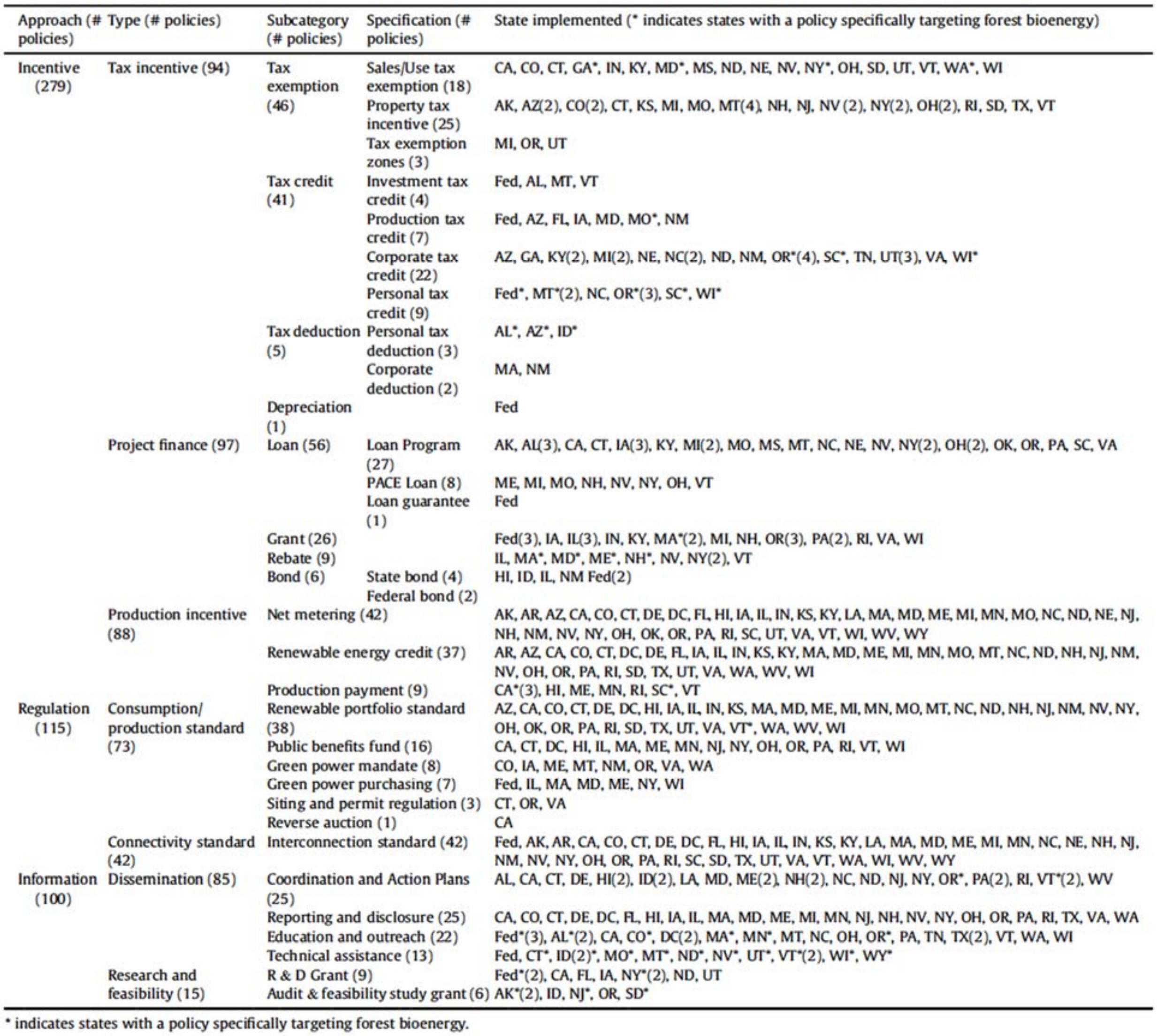
5.8. Appendix A:

Ebers et al. (2016) Classification of State's Policy Approaches for Forest Biomass Production.



Approach (# policies)	Type (# policies)	Subcategory (# policies)	Specification (# policies)	State implemented (* indicates states with a policy specifically targeting forest bioenergy)
Incentive (279)	Tax incentive (94)	Tax exemption (46)	Sales/Use tax exemption (18)	CA, CO, CT, GA*, IN, KY, MD*, MS, ND, NE, NV, NY*, OH, SD, UT, VT, WA*, WI
			Property tax incentive (25)	AK, AZ(2), CO(2), CT, KS, MI, MO, MT(4), NH, NJ, NV (2), NY(2), OH(2), RI, SD, TX, VT
			Tax exemption zones (3)	MI, OR, UT
		Tax credit (41)	Investment tax credit (4)	Fed, AL, MT, VT
			Production tax credit (7)	Fed, AZ, FL, IA, MD, MO*, NM
			Corporate tax credit (22)	AZ, GA, KY(2), MI(2), NE, NC(2), ND, NM, OR*(4), SC*, TN, UT(3), VA, WI*
			Personal tax credit (9)	Fed*, MT*(2), NC, OR*(3), SC*, WI*
		Tax deduction (5)	Personal tax deduction (3)	AL*, AZ*, ID*
			Corporate deduction (2)	MA, NM
		Depreciation (1)		Fed
	Project finance (97)	Loan (56)	Loan Program (27)	AK, AL(3), CA, CT, IA(3), KY, MI(2), MO, MS, MT, NC, NE, NV, NY(2), OH(2), OK, OR, PA, SC, VA
			PACE Loan (8)	ME, MI, MO, NH, NV, NY, OH, VT
			Loan guarantee (1)	Fed
		Grant (26)		Fed(3), IA, IL(3), IN, KY, MA*(2), MI, NH, OR(3), PA(2), RI, VA, WI
		Rebate (9)		IL, MA*, MD*, ME*, NH*, NV, NY(2), VT
		Bond (6)	State bond (4)	HI, ID, IL, NM Fed(2)
			Federal bond (2)	
	Production incentive (88)	Net metering (42)		AK, AR, AZ, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, NC, ND, NE, NJ, NH, NM, NV, NY, OH, OK, OR, PA, RI, SC, UT, VA, VT, WI, WV, WY
		Renewable energy credit (37)		AR, AZ, CA, CO, CT, DC, DE, FL, IA, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, OH, OR, PA, RI, SD, TX, UT, VA, WA, WV, WI
		Production payment (9)		CA*(3), HI, ME, MN, RI, SC*, VT
Regulation (115)	Consumption/ production standard (73)	Renewable portfolio standard (38)		AZ, CA, CO, CT, DE, DC, HI, IA, IL, IN, KS, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, NY, OH, OK, OR, PA, RI, SD, TX, UT, VA, VT*, WA, WV, WI
		Public benefits fund (16)		CA, CT, DC, HI, IL, MA, ME, MN, NJ, NY, OH, OR, PA, RI, VT, WI
		Green power mandate (8)		CO, IA, ME, MT, NM, OR, VA, WA
		Green power purchasing (7)		Fed, IL, MA, MD, ME, NY, WI
		Siting and permit regulation (3)		CT, OR, VA
		Reverse auction (1)		CA
	Connectivity standard (42)	Interconnection standard (42)		Fed, AK, AR, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, NC, NE, NH, NJ, NM, NV, NY, OH, OR, PA, RI, SC, SD, TX, UT, VA, VT, WA, WI, WV, WY
Information (100)	Dissemination (85)	Coordination and Action Plans (25)		AL, CA, CT, DE, HI(2), ID(2), LA, MD, ME(2), NH(2), NC, ND, NJ, NY, OR*, PA(2), RI, VT*(2), WV
		Reporting and disclosure (25)		CA, CO, CT, DE, DC, FL, HI, IA, IL, MA, MD, ME, MI, MN, NJ, NH, NV, NY, OH, OR, PA, RI, TX, VA, WA
		Education and outreach (22)		Fed*(3), AL*(2), CA, CO*, DC(2), MA*, MN*, MT, NC, OH, OR*, PA, TN, TX(2), VT, WA, WI
		Technical assistance (13)		Fed, CT*, ID(2)*, MO*, MT*, ND*, NV*, UT*, VT*(2), WI*, WY*
	Research and feasibility (15)	R & D Grant (9)		Fed*(2), CA, FL, IA, NY*(2), ND, UT
		Audit & feasibility study grant (6)		AK*(2), ID, NJ*, OR, SD*

* indicates states with a policy specifically targeting forest bioenergy.

6. Virginia

6.1 Executive Summary

The impact of new bioenergy production on carbon emissions in Virginia is a function of existing energy production and consumption, forest growth and respiration, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to establish the reference baseline condition for Virginia. Net carbon emissions associated with the hypothetical decommissioning of exiting bioenergy facilities in the state is estimated from 2014 to 2035. These data may be used for establishing criteria for incorporating forest feedstocks into state and national greenhouse gas (GHG) accounting frameworks.

Model Parameters and Inputs

The SubRegional Timber Supply (SRTS) model is a timber market projection system, solving for a recursive product market equilibrium using market parameters derived from econometric studies, forest dynamics based on USDA Forest Service data, and exogenous demand forecasts (e.g., Abt et al. 2009; Prestemon and Abt 2002). It utilizes field inventory and timber product output data from the US Forest Inventory and Analysis (FIA) program to characterize resource conditions and harvest activity. The advantage of this modeling approach is that projections are based on observed harvest-price-inventory relationships within the region, avoiding the need to exogenously establish market behavior (e.g., profit maximization).

The carbon emissions analyzed here are a function of landscape live-tree carbon and power plant emissions from the combustion of biomass for energy generation. Landscape carbon is based on (1) forest growth and respiration (i.e., forest structure is a function of change in age class over time, decay, mortality), (2) removals (e.g., harvests, timber stand improvement and restoration projects), and (3) fire, disturbance (e.g. hurricanes), insects, and diseases infestations. The location of carbon emissions is further influenced by forest products market dynamics driving competition and subsequent feedstock purchasing behavior. This dynamic will affect the location and intensity of forest harvesting, which affects subsequent forest growth and respiration.

In consultation with Virginia forestry and energy stakeholders, the four scenarios set out in the table below were selected to model net change in forest land use and carbon emissions by decommissioning three existing Dominion bioenergy facilities and one Northern Virginia Electric Cooperative facility. The analysis models the effect of one, two, three, or all four facilities ceasing operations from a loss of renewable electricity production tax credits, assumed to expire 10 years after the 2013 in-service date. The three Dominion facilities are 51 MW and each consume about 650,000 green tons of biomass per year. The Northern Virginia Electric Cooperative facility is 49.9 MW, and consumes about 600,000 green tons per year, but is sized at 51 MW for consistency across model runs. Biomass feedstocks are assumed 10% pulpwood and 90% non-pulpwood residue for all four facilities, procured from areas having available feedstock in the state regardless of facility location. The reference case assumes a modified baseline using year 2011 TPO data and continued, indefinite operation. The heat content is assumed 8,400 BTU per dry pound of feedstock, and an electricity-only heat rate (efficiency) of 27% for each facility.

We do not assume that forest biomass is carbon neutral. Rather, forest carbon is accounted for in real-time. A net increase in GHG emissions occurs when forest carbon storage in a bioenergy scenario is lower than that of the baseline. Alternatively, a net decrease in GHG emissions occurs when there is more forest carbon stored in the bioenergy scenario than in the baseline. In both bioenergy and baseline scenarios, forest carbon totals are aggregated from live tree, dead tree, understory, down dead, and forest floor pools. Owing to a variety of alternative fates, such as burning slash piles in pine systems to assist in site preparation, the short residence time of residues in hardwood or un-burned systems, or the possibility that residues not used for energy generation will be used for some other application, we assume that residues for energy production have a minimal influence on net forest carbon storage

Virginia modeled scenarios.

Scenario	2023	Key Assumptions
Virginia 1	51 MW	90% residues; decommissioning 1 facility in 2023
Virginia 2	2 - 51 MW	90% residues; decommissioning 2 facilities in 2023
Virginia 3	3 - 51 MW	90% residues; decommissioning 3 facilities in 2023
Virginia 4	3 - 51 MW, 1 – 49MW	90% residues; decommissioning 4 facilities in 2023

Model Scenarios Results

SRTS model runs suggest little change in forest product class harvest, price, or inventory over time, the exception being a projected downward pressure on prices in pine sawtimber. There is likewise little change between scenarios, or between scenarios and baseline runs. These trends are robust across scenarios, suggesting that observed trends are a function of larger resource and market dynamics, and have less to do with the operation of bioenergy facilities in the state. This is expected owing to the large proportion of feedstocks comprised of harvest residues.

The loss of bioenergy capacity is found to lead to a reduction in forest acreage across the state; the more facilities that close, the greater the loss of forest land. The disaggregated data shows that upland hardwood makes up a large portion of lost acreage, followed by plantation, mixed pine, natural pine and lowland hardwood, which mirrors the current mix of forest growing stock in the state. An increase in the number of plant retirements generally results in increased forest carbon storage owing to changes in land use, both in terms of forest extent and forest type, along with changes in land management and harvest decisions accompanying the reduced demand for forest products (Figure 6.6). Including the emissions associated with new natural gas electricity generation that would be expected to replace a reduction in bioenergy output, the net GHG benefit is found to vary both over time and by scenario.

Annualizing net emissions obscures year-over-year variation, but allows for quick comparison across scenarios. The table below shows power plant and terrestrial emissions by scenario (tCO_2/yr), and by MWh of electricity production. Scenario #4 yields the largest impact on total emissions, but lower than scenarios #2 and #3 on an MWh basis.

To understand the impact of any scenario, annual emissions from biomass need to be compared to annual emissions from the reference condition using fossil fuels to produce the same amount of energy (483,750 MWh/yr to 1,745,537 MWh/yr). Net change in projected forest carbon emissions were compared to the 10-year average in-state coal and natural gas carbon emissions to illustrate possible offsets by modeled scenario assuming lost biopower generation (scenarios #1-4) would be replaced with fossil fuel. Actual offsets would require comparison to future fossil fuel emissions. Positive values indicate net displacement of fossil fuel emissions, or decline in total emissions; negative values indicate a net increase in total emissions as a result of the scenario. Results illustrate that total carbon emissions would be less if biopower was retained than compared to the 10-year average fossil fuel replacement for all but scenario #2 with natural gas (-0.19 t CO_2/MWh). In other words, replacing that amount of lost biopower with coal would result in a net increase in emissions of between 0.47 t CO_2/MWh and 0.93 t CO_2/MWh, and for natural gas between -0.19 t CO2/MWh and 0.27 t CO_2/MWh.

Average annual net change in landscape forest carbon emissions, 2023-2035.

Scenario (% residues utilized)	Feedstock consumption (bdt/yr)	Power plant emissions (tonnes CO2/yr)	Energy generation (MWh/yr)	Virginia live tree emissions (tCO2/yr)	Virginia live tree energy intensity (tCO2/MWh)	Net fossil fuel energy intensity displacement (tCO2/MWh)*	
						Coal	NG
Virginia 1 (90%)	-325,000	-595,400	-438,750	-72,925	0.18	0.93	0.27
Virginia 2 (90%)	-650,000	-1,190,800	-877,500	-510,101	0.64	0.47	-0.19
Virginia 3 (90%)	-975,000	-1,786,200	-1,316,250	-531,173	0.44	0.67	0.01
Virginia 4 (90%)	-1,292,990	-2,368,758	-1,745,537	-550,682	0.35	0.76	0.10

*Net change in average annual emissions comparing bioenergy scenarios (years 2019-2035) to coal and natural gas (NG) (years 2006-2015). Positive values indicate a net decrease in total emissions; negative values indicate a net increase in total emissions.

Conclusion

The impact of a change in bioenergy capacity in Virginia is influenced by the proportion of logging residues that goes unutilized when decommissioning bioenergy facilities. SRTS model runs project a decrease in pine sawtimber prices across all scenarios, but little change in inventory or harvest removals across species, which is robust across scenarios suggesting that trends are a function of larger resource and market dynamics, and have less to do with the operation or decommissioning of bioenergy facilities in Virginia. The loss of bioenergy facilities does have an effect on forest acreage and land use; a loss in capacity is associated with a decline in forest area relative to the base case. As reported, changes are projected to have direct effects on landscape forest carbon, but the total GHG implications of changes in energy systems requires that net forest emissions be compared against a reference condition in which fossil fuels or other generation technologies are used. Projected forest emissions were compared to the 10-year in-state coal and natural gas emissions (2006-2015) to illustrate possible carbon offsets by modeled scenario. But comparison to future fossil fuel emissions was beyond the scope of this analysis and remains an important area for further research.

6.2. Introduction

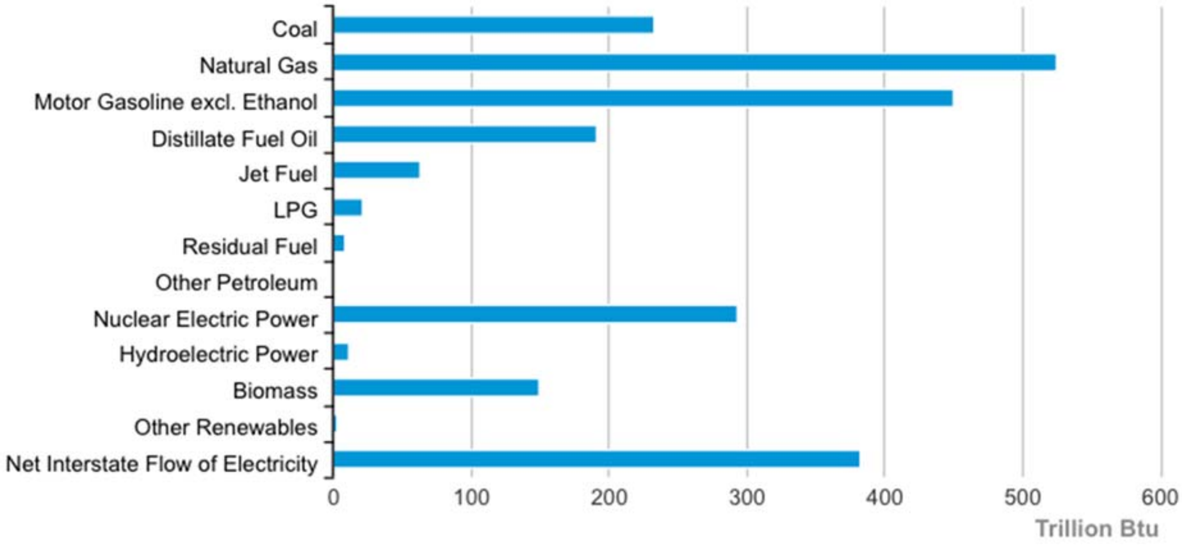
The impact of new bioenergy production on carbon emissions in Virginia is a function of existing energy production and consumption, forest growth and respiration, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to establish the reference baseline condition for Virginia. Net carbon emissions from adding new electricity generation using forest feedstocks is estimated from 2014 to 2035. These data may be used for establishing criteria for incorporating forest feedstocks into state and national greenhouse gas (GHG) accounting frameworks.

6.3. Virginia Energy Profile

6.3.1. Energy Production and Consumption

State energy profiles are comprised of energy production, energy consumption, and energy imports, which are a function of price and availability.[36] In 2015, the most recent year comprehensive US Energy Information Agency (EIA) data is available,[37] Virginia's primary energy production included coal (365.8 trillion British Thermal Units (Btu)), natural gas (134.2 trillion Btu), and crude oil (0.1 trillion Btu), as well as nuclear electricity power (293.5 trillion Btu) and renewable energy (134.8 trillion Btu) (EIA 2017a, Table P2), namely hydroelectric power, biomass (including biofuels), and other renewables (EIA 2017a; Table P2; EIA 2017c). The state consumed 2,367.7 trillion Btu of energy in 2015 (Figure 6.1), of which 1,439.4 trillion Btu was produced from imports of primary energy production and their derivatives from other states (EIA 2017a, Table P3), including 382.1 trillion Btu imported in the form of electricity from other states (EIA 2017b, Table C1).

Figure 6.1. Virginia Energy Consumption Estimates, 2015 (Source: EIA 2017c).



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[36] Since energy prices are fairly volatile, this report does not include price information. Historic (1970-2015) energy price information is available at: https://www.eia.gov/state/seds/sep_prices/notes/pr_print.pdf.

[37] As of October 2017.

6.3.2. Electricity Production and Consumption

In 2015, Virginia produced 84.4 million megawatt hours (MWh) of electricity (EIA 2016a), which was 15.5 percent more than produced in 2006 (Table 6.1). The majority of that electricity was produced from fossil fuels, namely coal (20.4%) and natural gas (39.4%), with nuclear power (33.2%) providing most of the remaining production (EIA 2016a). Five percent of electricity generated was from renewable energy sources, with wood and wood derived fuels providing 3.6 percent and hydropower 1.4 percent (EIA 2016a). Total annual emissions across all energy sources averaged 0.50 tCO2/MWh. Coal derived energy produced the majority of emissions averaging 1.11 tCO2/MWh per year.

Table 6.1. Electricity Generation and Emissions for Virginia, by Energy Source* (Source: EIA 2016a).

Year	Coal	Natural Gas	Nuclear	Hydro	Pumped Storage***	Wood and Wood Derived Fuels	Total**	CO2 Emissions (Mt CO2)	Energy Intensity (tCO2/MWh)
	Million megawatt hours								
2006	34.3	7.2	27.6	1.4	-1.2	1.8	73.1	42.5	0.58
2007	35.4	10.9	27.3	1.2	-1.6	1.8	78.4	47.2	0.60
2008	31.8	9.3	27.9	1.0	-1.6	1.9	72.7	41.4	0.57
2009	25.6	12.2	28.2	1.5	-1.3	1.7	70.1	36.2	0.52
2010	25.5	17.0	25.5	1.5	-1.5	1.4	73.0	39.7	0.54
2011	19.9	18.3	25.5	1.2	-1.5	1.4	66.7	32.6	0.49
2012	14.2	25.0	28.7	1.0	-1.4	1.4	70.7	29.2	0.41
2013	21.2	29.3	22.7	1.3	-1.2	1.9	76.9	34.7	0.45
2014	20.8	20.9	30.2	1.0	-1.3	2.8	77.1	33.7	0.44
2015	17.2	33.3	28.1	1.2	-1.0	3.0	84.4	34.9	0.41
	Energy intensity (tCO2/MWh)								
10-yr avg	1.11	0.45	0.0	0.0	0.0	0.0	0.50	--	--

* Table omits energy sources that produced an average of 1 million MWh or less per year during these 10 years. This included "Petroleum" (which produced an average of 1 million MWh per year), "Other Biomass" (averaged: 0.9 million MWh/year), and "Other" sources (averaged: 0.5 million MWh/year).

** Row totals may not add up due to rounding and sources omitted in accordance with previous note.

*** Pumped storage is negative because "more electricity is used to force the water uphill … than is produced when it flows downhill during the day" (EIA 2013).

Virginia's electricity generators and combined heat and power (CHP) generators produced 84.4 million MWh of electricity in 2015. Electricity generators produced the vast majority of this (79.8 million MWh; 94.5% of all generation), of which electricity utilities generated 67.6 million MWh and independent power producers generated 12.2 million MWh (EIA 2016a). CHP facilities generated only 4.8 million MWh of the state's electricity – industrial power CHPs generated 2.5 million MWh, and electric power CHPs and commercial power CHPs generated 1.8 million MWh and 0.5 million MWh, respectively (EIA 2016a).

Of the 112 million MWh of electricity consumed in Virginia in 2015, 27.6 million MWh was imported (EIA 2016a; EIA 2016b). The largest shares of electricity used within the state was by the commercial (43.2%) and residential (41%) sectors. The industrial sector consumed 15.7 percent and the transportation sector consumed 0.2 percent of this electricity (EIA 2016b).

6.3.3. Electricity from Forest Biomass Resources. In 2015, net electricity generation from forest biomass, using EIA's Wood and Wood Derived Fuel definition,[38] provided more than 3 million MWh (3.6%) of Virginia's electricity (Table 6.2) – more than any other sources besides coal, natural gas, and nuclear (Table 6.1) (EIA 2016a). Forest biomass-based electricity generation increased 70.8 percent from 2006 to 2015, with 52.2 percent of that electricity in 2015 produced by industrial power CHP facilities (EIA 2016a).

Table 6.2. Virginia Net Generation from "Wood and Wood Derived Fuels" by Type of Producer and Year in thousand megawatt hours (Source: EIA 2016a).

Year	Combined Heat and Power			Electricity Generators		Total
	Industrial Power	Commercial Power	Electricity Power	Independent Power Producers	Electricity Utilities	
2006	1,297.3	0	0	0	482.7	**1,780**
2007	1,333.2	0	0	0	459.2	**1,792.3**
2008	1,409.5	0	0	0	506.8	**1,916.3**
2019	1,267.7	0	0	0	440.6	**1,708.3**
2010	981.5	0	0	0	422.8	**1,404.3**
2011	1,000.9	0	0	0	405.1	**1,406**
2012	1,094.6	0	0	0	341.2	**1,435.8**
2013	1,237.3	0	0	39.1	669.9	**1,946.2**
2014	1,423.5	0	0	202.6	1,128.6	**2,754.8**
2015	1,587.3	0	0	255.3	1,198.6	**3,041.1**

6.3.4. Biomass Thermal Heat Generation

In 2015, heat from wood, wood-derived fuels, and biomass waste[39] was used in Virginia's residential, commercial, and industrial sectors (Table 6.3) (EIA 2017b). EIA estimated that thermal uses (81.2 trillion Btu) of these materials in the state were 2.4 times greater than the 33.6 trillion Btu from the use of this biomass to produce electricity (EIA 2017b, Tables CT3 and CT8),[40] and that Virginia's thermal use of forest biomass decreased 12.4 percent from 2006 to 2015.

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[38] EIA (2017d) defines Wood and Wood-Derived Fuels as "Wood/Wood Waste Solids (including paper pellets, railroad ties, utility poles, wood chips, bark, and wood waste solids)[,] Wood Waste Liquids (excluding Black Liquor but including red liquor, sludge wood, spent sulfite liquor, and other wood-based liquids)[, and] Black Liquor. *Note:* EIA's (2017d) "Other Biomass" category includes other types of biomass, such as "Agricultural By-Products[,] Municipal Solid Waste[,] Other Biomass Gas (including digester gas, methane, and other biomass gases) [,] Other Biomass Liquids[,] Other Biomass Solids[,] Landfill Gas[, and] Sludge Waste. However, since this report's modeling focuses on forest biomass and its derivatives, this report focuses exclusively on EIA's Wood and Wood-Derived Fuels.

[39] EIA (2017d) defines biomass waste as "[o]rganic non-fossil material of biological origin that is a byproduct or a discarded product. Biomass waste includes municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural crop byproducts, straw, and other biomass solids, liquids, and gases; but excludes wood and wood-derived fuels (including black liquor), biofuels feedstock, biodiesel, and fuel ethanol. Note: EIA biomass waste data also include energy crops grown specifically for energy production, which would not normally constitute waste." *Note:* This definition differs from EIA's definition of "Other Biomass" – see previous footnote.

[40] "The electric power sector comprises electricity-only and combined-heat-and-power (CHP) plants ... whose primary business is to sell electricity, or electricity and heat, to the public" (EIA 2017b, 441).

Table 6.3. Virginia's Energy Consumption Estimates for Thermal and Electricity Power from "Wood, Wood-Derived Fuel, and Biomass Waste" by Year and Type of Producer in trillion Btu (Source: EIA 2017b, Tables CT2, CT3, CT4, CT5, CT6, CT8).

Year	Thermal Power (trillion Btu)				Electricity Power (trillion Btu)	Total Consumption (trillion Btu)
	Residential Sector (thousand cords*)	Commercial Sector	Industrial Sector	Thermal Total		
2006	13.5 (674)	8.2	69.9	91.6	12.5	**104.1**
2007	14.9 (745)	7.6	67.4	89.9	13.1	**103**
2008	16.7 (834)	7.5	65.3	89.6	16.2	**105.8**
2009	16.2 (808)	6.9	59.8	82.9	15.7	**98.6**
2010	14.1 (705)	7.1	49.0	70.2	16.3	**86.5**
2011	14.4 (721)	6.6	48.4	69.5	15.9	**85.4**
2012	13.5 (673)	6.9	49.0	69.4	17.2	**86.6**
2013	18.6 (930)	7.4	51.9	77.9	22.1	**100.0**
2014	18.9 (947)	7.4	56.2	82.5	33.0	**115.5**
2015	14.1 (705)	7.5	59.5	81.2	33.6	**114.7**

* EIA only estimated cord wood usage for this sector (EIA 2017b, Table CT4).

6.3.5. State Energy Choices

State energy policy choices are based on local, state, regional, and national goals, such as economic development, energy security, energy reliability (e.g., base and peak load capacity), energy prices, and air pollution emissions, including greenhouse gas emissions. These policies influence states' energy mixes and can cause energy producers and consumers to favor one or more energy sources over others. As Ebers et al. (2016, 67) noted as of "September 2013, federal and state governments had created 494 policies to support production of electricity and heat from forest biomass." Building on Becker et al. (2011), Ebers et al. (2016, 67) developed "a four-tier classification structure to categorize policy instruments based on: approach (incentive, regulation, information), type (e.g. tax incentive), subcategory (e.g. tax exemption), and specification (e.g. sales tax exemption)" (see Appendix A).

According to Ebers et al. (2016) in 2013, Virginia did not utilize any policy approaches focused on stimulating forest biomass energy. However, other incentives specific to renewable energy, but not limited to electricity or heat produced from forest biomass, included corporate tax credits, loan programs, grants, net metering, renewable energy credits, renewable portfolio standard, green power mandate, siting and permit regulations, interconnection standards, and reporting and disclosure, (Ebers et al. 2016).[41]

6.3.6. Biomass Energy CO_2 and Other Emissions

State energy choices regarding fossil fuels and renewables to produce heat and electricity have CO_2 and other emission implications. Emissions from biomass energy generation vary greatly depending on the feedstock source, location, conversion efficiency, and other factors. Combining heat with electricity production significantly increases efficiency over standalone electricity production and reduces GHG emissions per unit of energy generation, while dried forest biomass (e.g., pellets and dried wood chips) will provides higher conversion efficiencies than green wood chips (Schlamadinger et al. 1997). Feedstock proximity, which affects greenhouse gas emissions from biomass transportation also impacts emissions, with biomass facilities price- and volume-constrained based on feedstock availability and competition from other biomass users (Schlamadinger et al. 1997, Galik et al. 2009).

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[41] The policy approaches reported in this paragraph use Ebers et al.'s (2016) policy names/terminology.

In 2015, electricity production from *all sources* in Virginia produced an estimated 34.9 million metric tons of CO_2, 30,606 metric tons of SO_2, and 34,469 metric tons of NO_X (EIA 2016c). Of these emissions, wood and wood-derived fuels produced 24.4 percent of the state's SO_2 emissions, and 5.9 percent of its NO_X emissions (Table 6.4) (EIA 2016c). Because the EIA follows current international convention and assumes that CO_2 "released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions" (EIA 2011), *none* of Virginia's estimated CO_2 electricity emissions include CO_2 emissions from biomass.[42]

Table 6.4. Virginia Estimated Emission from "Wood and Wood-Derived Fuel" by Type of Producer in metric tons (Source: EIA 2016c).

Year	Emission	Electric Utility	Independent Power Producers		Commercial		Industrial		Total
			Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	
2006	SO_2	68	0	0	0	0	1	13,879	**13,948**
	NO_x	333	0	0	0	0	9	1,318	**1,660**
2007	SO_2	64	0	0	0	0	0	13,160	**13,224**
	NO_x	315	0	0	0	0	0	1,387	**1,702**
2008	SO_2	99	0	0	0	0	0	12,991	**13,090**
	NO_x	497	0	0	0	0	0	1,328	**1,825**
2009	SO_2	90	0	0	0	0	0	11,681	**11,771**
	NO_x	448	0	0	0	0	0	1,177	**1,625**
2010	SO_2	84	0	0	0	0	0	8,861	**8,945**
	NO_x	420	0	0	0	0	0	1,477	**1,897**
2011	SO_2	80	0	0	0	0	0	8,354	**8,434**
	NO_x	394	0	0	0	0	0	1,519	**1,913**
2012	SO_2	70	0	0	0	0	0	8,798	**8,868**
	NO_x	344	0	0	0	0	0	1,561	**1,905**
2103	SO_2	89	5	0	0	0	0	9,460	**9,554**
	NO_x	2,101	4	0	0	0	0	1,398	**3,503**
2014	SO_2	102	37	0	0	0	0	9,175	**9,314**
	NO_x	866	33	0	0	0	0	1,324	**2.223**
2015	SO_2	90	45	0	0	0	0	7,336	**7,473**
	NO_x	870	40	0	0	0	0	1,125	**2,035**

While international convention and the EIA assume that "the CO_2 released from biofuel or bioenergy combustion … [is] fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy," (EIA 2011, 60) from a landscape perspective forests can be a CO_2 sink, CO_2 source, or carbon neutral (Malmsheimer et al. 2008). Forests are a CO_2 sink when live and dead vegetation, litter, and soil sequester more carbon than emitted, and forests are a carbon source when these emissions exceed sequestration rates (Wear and Coulston 2015). Management actions such as timber harvesting, or natural disturbances like wildfires affecting the CO_2 balance determines the extent

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[42] As EIA notes, "According to current international convention, CO_2 released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions. The related fossil fuel emissions from the transportation and processing of the biological feedstocks are captured within overall energy sector emissions, but currently they are not allocated to the biofuels. Additionally, the CO_2 released from biofuel or bioenergy combustion is assumed to be fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy. However, analysts have debated whether the increased use of biomass energy may result in a loss of terrestrial carbon stocks and foregone future sequestration by natural vegetation. The initial loss of carbon stocks in natural vegetation cleared to grow biomass feedstocks and the foregone future removal of CO_2 are not captured in energy sector emissions. To capture the potential net emissions, the international convention for GHG inventories is to report the net carbon flux from land use change (such as when forests are converted to cropland to grow feedstocks) in the Land Use category. Although accounting for land use emissions is more challenging than for most of the other emissions sources, emissions and sequestration associated with domestic U.S. land use change should in principle be accounted for in this chapter of the inventory report. However, from a global greenhouse gas emissions perspective, the key uncertainty regarding aggregate net biogenic emissions is indirect land use change that occurs abroad." (EIA 2011).

to which a forest is a net sink or source of CO_2 to the atmosphere (Woodall et al. 2015). Carbon is also sequestered in harvested wood products, such as lumber and paper, which affects the CO_2 balance (EIA 2011; Malmsheimer et al. 2008). At the end of a products' useful life, the carbon is either released directly into the atmosphere through burning and energy combustion (Malmsheimer et al. 2011; Miner et al. 2014), or natural decomposition or decay in landfills (Skog 2008).[43]

While most forest-based carbon is eventually released into the atmosphere, forest products and forest biomass energy provide documented benefits. As Malmsheimer et al. (2011, S9) described, "[f]orest products used in place of energy intensive materials such as metals, concrete and plastics (a) reduce carbon emissions (because forest products require less fossil fuel-based energy to produce), (b) store carbon (for a length of time based on products' use and disposal), and (c) provide biomass residuals (i.e., waste wood) that can be substituted for fossil fuels to produce energy. [In addition,] [f]ossil fuel–produced energy releases carbon into the atmosphere that has resided in the Earth for millions of years; forest biomass–based energy uses far less of the carbon stored in the Earth thereby reducing the flow of fossil fuel–based carbon emissions to the atmosphere."

6.4. Forest Sector Profile

6.4.1. The Condition of the Forest Resource

As a lower value commodity relative to sawlogs and other forest products, the availability of biomass for energy generation often depends on traditional forest products markets to generate sufficient financial incentive to enable biomass removal (Oswalt et al. 2018; Miner et al. 2014). These markets depend in large part on the condition of a state's forest resource, species composition, and forest products manufacturing base.

Nearly two-thirds (63.5%) of Virginia is forested, and the number of acres has increased slightly since 2011 (Table 6.5) (Oswalt et al. 2014; 2018). Almost 83 percent of the state's timberlands – forests producing or capable of producing industrial wood, and not withdrawn from timber utilization – have natural origins, as opposed to being planted (Oswalt et al. 2018).

Table 6.5. Virginia Land Area, by Year, in thousands of acres (Sources: Oswalt et al. 2014; 2018 (Tables 1a)).

Year	Total Land Area	Forestland*					Woodland****	Other Land
		Total	Timberland**		Reserved***	Other		
			Planted	Natural Origin				
2011	25,274	15,907	2,553	12,832	486	36	0	9,367
2017	25,274	16,043	2,656	12,733	562	92	0	9,231

* Forestland is defined as, "Land at least 120 feet (37 meters) wide and at least 1 acre (0.4 hectares) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. The definition here includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest land also includes transition zones, such as areas between forest and nonforest lands that have at least 10 percent cover (or equivalent stocking)

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[43] As Malmsheimer et al. (2011, S30), noted "Of the wood products that enter solid waste disposal sites, more than three quarters of the carbon in solid wood and almost one-half of the carbon in paper is never released to the atmosphere … . The carbon that is released during decay takes many years to reach the atmosphere. For example, the 23% of the solid wood that does decay has a half-life of 29 years. Skog (2008) found that when paper is landfilled, the nonlignin component (56%) decays, leaving the lignin component (44%) as a long-term store in the landfill … . This nondegradable fraction varies by grade, from approximately 10% for bleached chemical pulp fibers to 85% for mechanical pulp fibers (US EPA 2006)."

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with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (37 meters) wide or an acre in size. Forest land does not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

** Timberland is defined as, "Forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. (Note: Areas qualifying as timberland are capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.)" (U.S. Forest Service 2017a).

*** Woodland is defined as, "a class of land which consists predominantly of stands of sparse woodland species such as juniper, pinyon juniper, mesquite and small stature hardwood species and are found in the arid to semiarid regions of the interior western United States. These areas must span more than 1 acre (0.4 hectares, have sparse trees capable of achieving 16.4 feet (5 meters) in height in situ, and a tree canopy cover of 5 to 10 percent. When combined with shrubs and bushes these areas may achieve overall cover greater than 10 percent woody vegetation. Trees are defined as woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. These areas do not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

**** Reserved Forestland is defined as, "Land permanently reserved from wood products utilization through statute or administrative designation. Examples include National Forest wilderness areas and National Parks and Monuments." (U.S. Forest Service 2017a).

Hardwoods constitute 73.1 percent of Virginia's timberlands (Table 6.6) (Oswalt et al. 2018). Most (71%) of the state's estimated 940 million dry tons of above ground biomass is in the boles of live trees with a diameter at breast height of 5 or more inches, 16.4% in the tops and limbs and 4.1% in stumps (Oswalt et al. 2018). Saplings contain 7.1% of above ground biomass and sound dead biomass, which the U.S. Forest Service defines as salvageable dead trees, comprises 1.3% of all such biomass in the state (U.S. Forest Service 2017a).

Table 6.6. Virginia Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 (Source: Oswalt et al. 2018 (Tables 17 and 38a)).

Growing Stock Volume *(in million cubic feet)*			**Above Ground Biomass** *(in million dry tons)*						
			Total Biomass	**Live Tree Biomass**					**Sound Dead Biomass**
				Greater than 5-inches DBH			**Sapling Biomass**	**Woodland Species**	
Total	**Softwood**	**Hardwood**		**Boles**	**Stumps**	**Tops/Limbs**			
31,654	8,502	23,152	953	677	39	156	68	0	12

Data may not add to totals because of rounding.

In 2017, net growth exceeded mortality and removals in Virginia timberland by more than 1 billion cubic feet (Table 6.7), and net growth increased 9.1 percent from 2011 to 2017 (Oswalt et al. 2014; 2018). Fifty-seven percent of net growth in 2017 occurred in hardwoods (Table 6.7).

Table 6.7. Virginia Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in thousand cubic feet (Source: Oswalt et al. 2014; 2018 (Table 36)).

	All Species			**Softwoods**			**Hardwoods**		
	Net growth	**Removals**	**Mortality**	**Net growth**	**Removals**	**Mortality**	**Net growth**	**Removals**	**Mortality**
2011	972,770	622,648	199,860	382,656	279,588	86,307	590,113	343,060	113,553
2017	1,061,109	464,313	214,186	455,818	253,166	79,409	605,291	211,146	134,776

* "[N]et annual growth [is t]he average annual net increase in the volume of trees during the period between inventories. Components include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year and minus the net volume of trees that became cull trees during the year" (Oswalt 2014, 33). Thus, net annual growth includes mortality, but does not include removals, so removals must be subtracted from net growth to calculate increases or decreases in growing stock *in the forest*.

Non-industrial owners, also known as family forest owners, own 62.1 percent of Virginia's timberlands and industrial landowners own 20.2 percent (Table 6.8) (Oswalt et al. 2018). Public entities manage 17.7 percent of the state's timberlands, with the federal government administering 13.9 percent, the State of Virginia 2.2 percent, and counties and municipalities 1.6 percent.

Table 6.8. Virginia Timberland Area by Ownership, 2017, in thousands of acres (Source: Oswalt et al 2018 (Table 2)).

	Public					Private		Total
	Federal			State	County & Municipal	Industrial	Non-Industrial	
	National Forest	BLM	Other					
	1,693	0	533	348	264	3,241	9,963	
Subtotals	2,227							
Totals	2,839					13,204		16,043

Data may not add to totals because of rounding.

6.4.2. The Forest Industry

Slightly more than half of timber products manufactured in Virginia were produced from softwoods (Table 6.9.) (Source: Oswalt et al. 2014 (Table 39)). Private non-industrial forests (e.g., family forest owners) supplied the majority softwood-based (88.3%) and hardwood-based (86%) feedstocks. Saw logs represented 38.5 percent (by volume) of all of the state's timber products. Pulpwood (34.8%) was the only other product category using more than 10 percent of the in-state wood supply.

Table 6.9. Virginia Volume of Industrial Timber Products by Ownership Class and Timber Product, 2011, in millions of cubic feet (Source: Oswalt et al. 2014 (Table 39); Forest Service 2017b).

Ownership Class	Total	Saw Logs	Veneer Logs	Pulpwood	Composite Products	Residential Fuelwood*	Post-Poles-Pilings	Other Industrial
Softwoods								
National Forests	55	51	0	1	2	1	0	0
Other Public	4,572	1,360	95	1,944	935	102	102	34
Forest Industry	22,217	7,765	1,183	9,731	2,408	499	105	524
Other Private	203,000	73,953	5,697	74,495	39,179	4,555	1,319	3,801
Softwoods Total	229,844	83,130	6,974	86,171	42,525	5,158	1,526	4,360
Hardwoods								
National Forests	3,259	1,814	68	681	2	676	1	18
Other Public	8,098	3,842	57	2,334	134	1,680	16	35
Forest Industry	11,522	4,129	85	4,388	146	2,389	5	380
Other Private	201,400	81,944	2,657	64,636	1,199	41,757	132	9,075
Hardwoods Total	224,278	91,728	2,867	72,039	1,481	46,501	154	9,508
Total Softwoods and Hardwoods	454,122	174,858	9,841	158,210	44,006	51,659	1,680	13,868

Numbers in rows and columns may not add to totals due to rounding.

* Residential Fuelwood is consumed for private use (U.S. Department of Energy estimates). Industrial fuelwood is included in Other Industrial.

6.5. Forest CO_2 Modeling

6.5.1. Model Parameters and Inputs

The SubRegional Timber Supply (SRTS) model is a timber market projection system, solving for a recursive product market equilibrium using market parameters derived from econometric studies, forest dynamics based on USDA Forest Service data, and exogenous demand forecasts (e.g., Abt et al. 2009; Prestemon and Abt 2002). It utilizes field inventory and timber product output data from the US Forest Inventory and Analysis (FIA) program to characterize resource conditions and harvest activity. The advantage of this modeling approach is that projections are based on observed harvest-price-inventory relationships within the region, avoiding the need to exogenously establish market behavior (e.g., profit maximization). A map of the distribution of Virginia's forest products facilities is presented in Figure 6.2.

The modeling parameters for each scenario were based upon documented harvest activity derived from TPO data. Harvests are assumed to come from forests identified as timberland by the USDA Forest Service's Forest Inventory and Analysis (FIA) program. Using FIA-derived ecosystem-level equations (Foley et al. 2009, as based on Smith and Heath 2002 and Smith et al. 2006), forest inventory projections in SRTS are converted into estimates of on-site forest carbon for each of the five management types by age class included in the model. Model projections focus on the state-level implications of a change in bioenergy demand; results show the implications of forest harvest change in Virginia only. It is possible that changes in demand from facilities in Virginia will have effects on harvest activity in adjoining states. It is equally possible, however, that harvests within Virginia are feeding markets in these other states. Limiting the model run to Virginia thus provides a reasonable indication of the changes in harvest dynamics and forest land use associated with new bioenergy demand given the composition of existing demand across product categories (Table 6.10). SRTS is most appropriately used to project near-term dynamics, so estimates are only provided for the first 20 years (2015-2035) of alternative bioenergy scenarios.

Table 6.10. Total number of wood using facilities, production capacity, and foreign trade for wood products in Virginia, 2014 (Source: Latta et al. 2018).

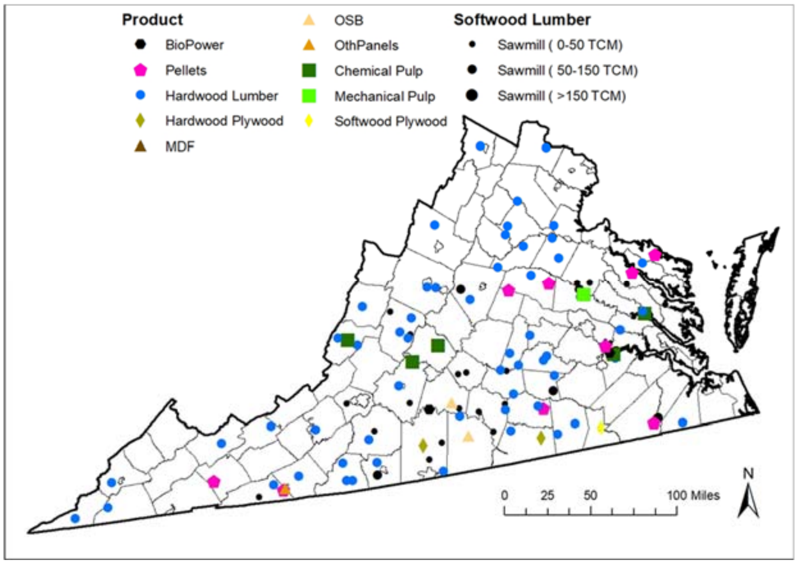
Forest Product		**Facilities**	**Capacity**	**Foreign trade***	
				Exports	**Imports**
		---- # ----	*----- million m^3 -----*	*---- million dollars ----*	
Roundwood	softwood			7.6	0.1
	hardwood			70.7	0.3
Lumber	softwood	32	820	13.4	14.2
	hardwood	58	980	286.1	35.6
Plywood	softwood	2	85	0.9	68.6
	hardwood	2	82		
Cross laminated timber (CLT)					
Oriented strand board (OSB)		2	1160	1.1	
Medium-density fibreboard (MDF)				1.5	1.1
Other panel products		1	38		
			-- million tonnes (Mt) --		
Pulp	chemical	5	2287	460.0	0.6
	mechanical	1	177	3.9	
Newsprint		1	1	252	31.8
Print and writing paper		2			10.5
Paperboard		3	7	3538	591.4
Tissue		3			1.6
Wood pellets		9	9	496	39.7
Chips	softwood			4.6	0.0
	hardwood			1.1	0.1
			------ MWh ------		
Forest biopower		3	32		
Forest co-firing		21	313		

*Port-level foreign trade data is 2010-2014 average from the United States International Trade Commission (USITC) Interactive Tariff and Trade Database (DataWeb), http://DataWeb.usitc.gov.

6.5.2. Virginia Model Scenarios

The carbon emissions analyzed here are a function of landscape live-tree carbon and power plant emissions from the combustion of biomass for energy generation. Landscape carbon is based on (1) forest growth and respiration (i.e., forest structure is a function of change in age class over time, decay, mortality), (2) removals (e.g., harvests, timber stand improvement and restoration projects), and (3) fire, disturbance (e.g. hurricanes), insects, and diseases infestations. The location of carbon emissions is further influenced by forest products market dynamics driving competition and subsequent feedstock purchasing behavior. This dynamic will affect the location and intensity of forest harvesting, which affects subsequent forest growth and respiration. Total emissions are thus a function of the following variables, which form the basis for the scenarios modeled in Virginia:

Figure 6.2. Virginia Primary Wood-Using Mills, by Region, 2014 (Source: Latta et al. 2018).



- Facility size and location – influences where the feedstock is procured, distance traveled, and price paid. The number and size of competing forest products industries within a procurement zone subsequently influences price and the distribution of feedstock by end product.
- Number of facilities – affects the distribution of feedstock demand, distance traveled, and associated emissions.
- Feedstock availability – function of land ownership, tree characteristics (species, size, age, and location), and projected growth and yield. Factors such as insect and fire mortality, or policy regulations will affect average annual harvest levels and availability by ownership.
- Feedstock type – the carbon emissions profile is influenced by the type of feedstock used for energy production. For instance, the ratio of clear-cutting to harvest thinnings, or the ratio of pulpwood to logging residuals influences carbon flux.
- Product demand – total wood products demand for the United States is assumed unchanged when adding bioenergy capacity. Total exports also remain static but the distribution of port activity and regional production changes with any new bioenergy.
- Conversion technology – changing the type of biopower facility and rated efficiency will affect the volume of feedstock needed to produce energy, which affects emissions. The type of offset fossil fuel (e.g., coal-fired power) and corresponding conversation efficiency is important.

In consultation with Virginia forestry and energy stakeholders, four scenarios (Table 6.11) were selected to model net change in forest land use and carbon emissions by decommissioning three existing Dominion bioenergy facilities and one Northern Virginia Electric Cooperative facility. The analysis models the effect of one, two, three, or all four facilities ceasing operations from a loss of renewable electricity production tax credits, assumed to expire 10 years after the 2013 in-service date. The three Dominion facilities are 51 MW and consume about 650,000 green tons of biomass per year. The Northern Virginia Electric Cooperative facility is 49.9 MW, and consumes about 600,000 green tons per year, but is sized at 51 MW for consistency across model runs. Biomass feedstocks are assumed 10% pulpwood and 90% non-pulpwood residue for all four facilities, procured from areas having available feedstock in the state regardless of facility location. The reference case assumes a modified baseline using year 2011 TPO data and continued, indefinite operation. The heat content is assumed 8,400 BTU per dry pound of feedstock, and an electricity-only heat rate (efficiency) of 27% for each facility.

Table 6.11. Virginia modeled scenarios.

Scenario	2023	Key Assumptions
Virginia 1	51 MW	90% residues; decommissioning 1 facility in 2023
Virginia 2	2 - 51 MW	90% residues; decommissioning 2 facilities in 2023
Virginia 3	3 - 51 MW	90% residues; decommissioning 3 facilities in 2023
Virginia 4	3 - 51 MW, 1 – 49MW	90% residues; decommissioning 4 facilities in 2023

We do not assume that forest biomass is carbon neutral. Rather, forest carbon is accounted for in real-time. A net increase in GHG emissions occurs when forest carbon storage in a bioenergy scenario is lower than that of the baseline. Alternatively, a net decrease in GHG emissions occurs when there is more forest carbon stored in the bioenergy scenario than in the baseline. In both bioenergy and baseline scenarios, forest carbon totals are aggregated from live tree, dead tree, understory, down dead, and forest floor pools. Owing to a variety of alternative fates, such as burning slash piles in pine systems to assist in site preparation, the short residence time of residues in hardwood or un-burned systems, or the possibility that residues not used for energy generation will be used for some other application, we assume that residues for energy production have a minimal influence on net forest carbon storage.

6.5.3. Virginia Model Scenarios Results

Price, inventory, and removal indices for a subset of bioenergy scenarios are shown in Figures 6.3 and 6.4. Each figure shows changes in the price, inventory, and removals for a particular forest product, indexed to the first year of the scenario to show relative change over time. Across all scenarios, SRTS model runs suggest little change in forest product class harvest, price, or inventory over time, the exception being a projected downward pressure on prices in pine saw timber, as indicated by the decline in price index in the pine sawtimber panels. There is likewise little change between scenarios, or between scenarios and baseline runs, suggesting that observed trends are a function of larger resource and market dynamics, and have less to do with the operation of bioenergy facilities in the state. Further evidence of this is the observed change in indices prior to any plant retirement and the continuation along pre-existing trends following plant retirement. This is not unexpected owing to the large proportion of feedstocks comprised of residues.

Figure 6.3. Price, inventory, and removal indices for multiple forest products, assuming loss of one (1) 51 MW bioenergy facility in 2023.

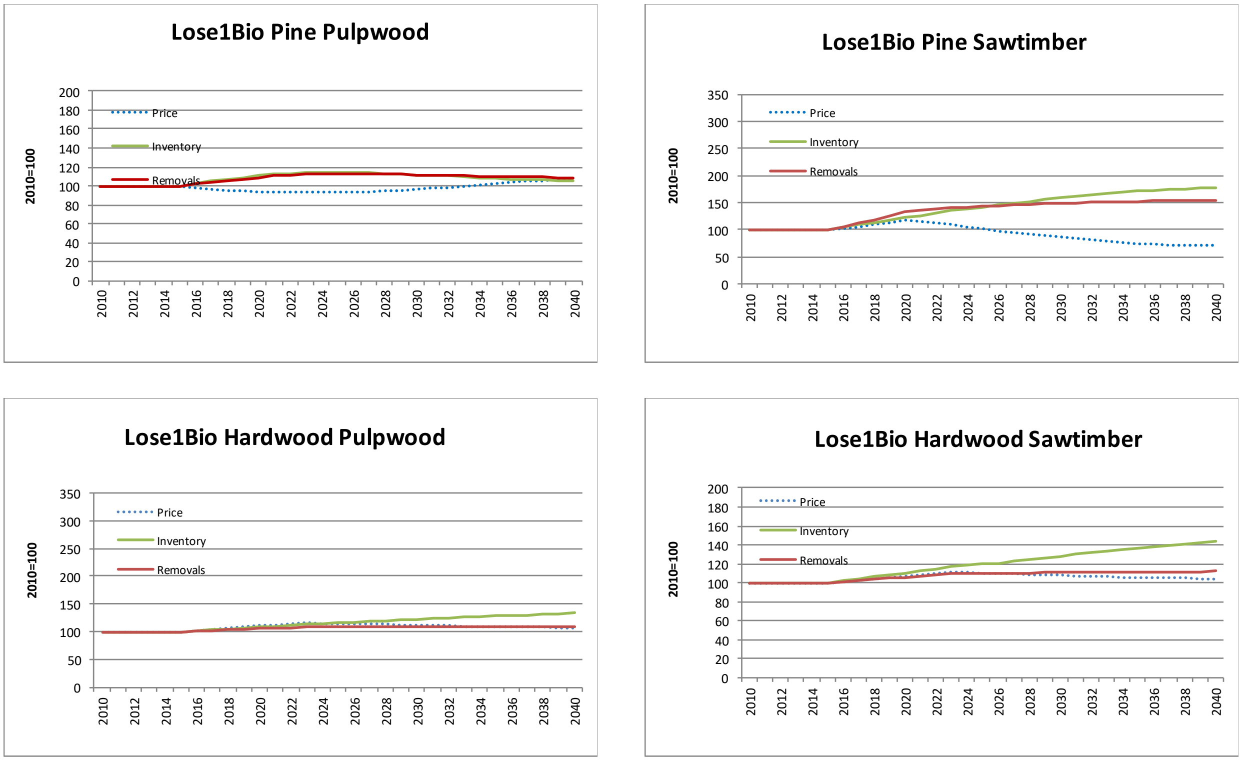
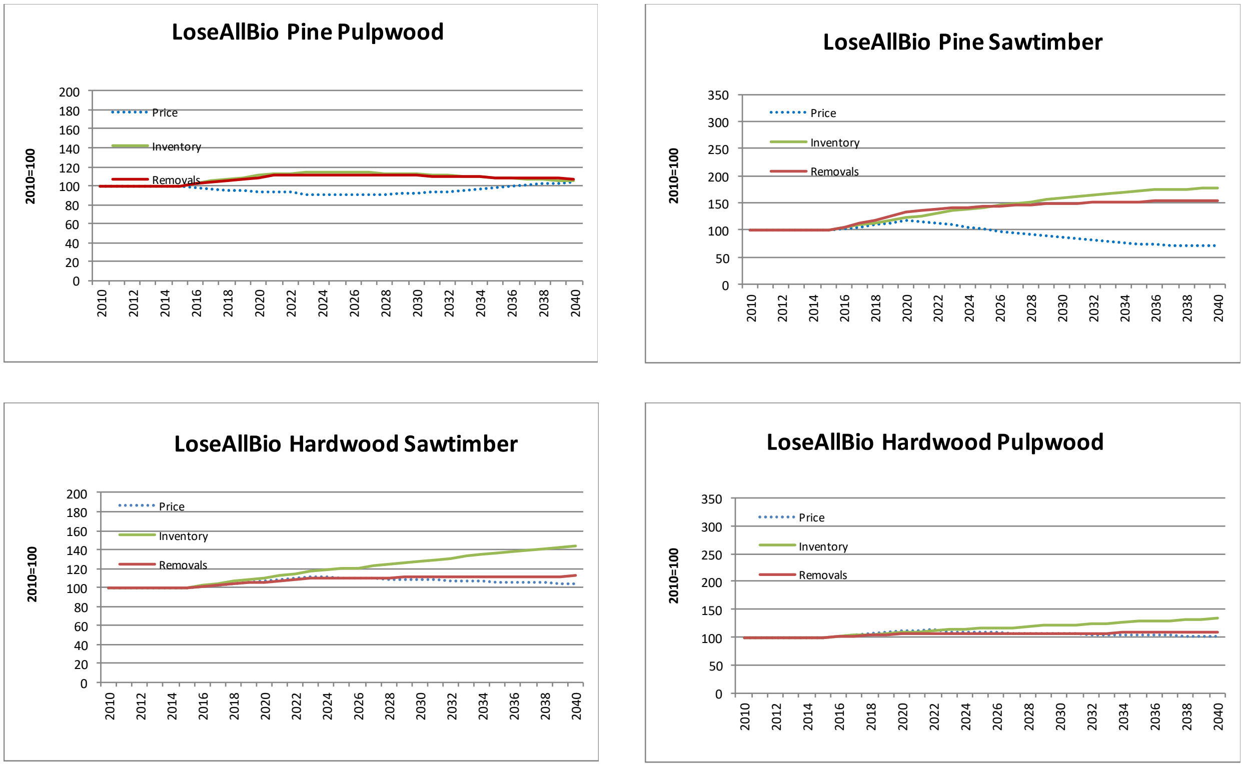


Figure 6.4. Price, inventory, and removal indices for multiple forest products, assuming the loss of four (4) 51 MW existing facilities in 2023.



The loss of bioenergy capacity is found to lead to a reduction in forest acreage across the state; the more facilities that close, the greater the loss of forest land (Figure 6.5). The disaggregated data shows that upland hardwood makes up a large portion of lost acreage, followed by plantation, mixed pine, natural pine and lowland hardwood, which mirrors the current mix of forest growing stock in the state. An increase in the number of plant retirements generally results in increased forest carbon storage owing to changes in land use, both in terms of forest extent and forest type, along with changes in land management and harvest decisions accompanying the reduced demand for forest products (Figure 6.6). The magnitude of change in forest markets leads to important differences across scenarios, however, with net change in the single retirement scenario being much less than the other three. These differences between scenarios, along with substantial changes in years 2028 and 2033 for the 2, 3, and 4-loss scenarios, suggest that the existence of market thresholds that, when crossed, lead to changes in land use and management, particularly in planted pine and upland hardwood forest types.

Annualizing net emissions obscures year-over-year variation, but allows for

Figure 6.5. Aggregate land use change in Virginia by scenario. Values above the x-axis represent an increase in forest land area relative to the baseline scenario; values below the x-axis represent a decline.

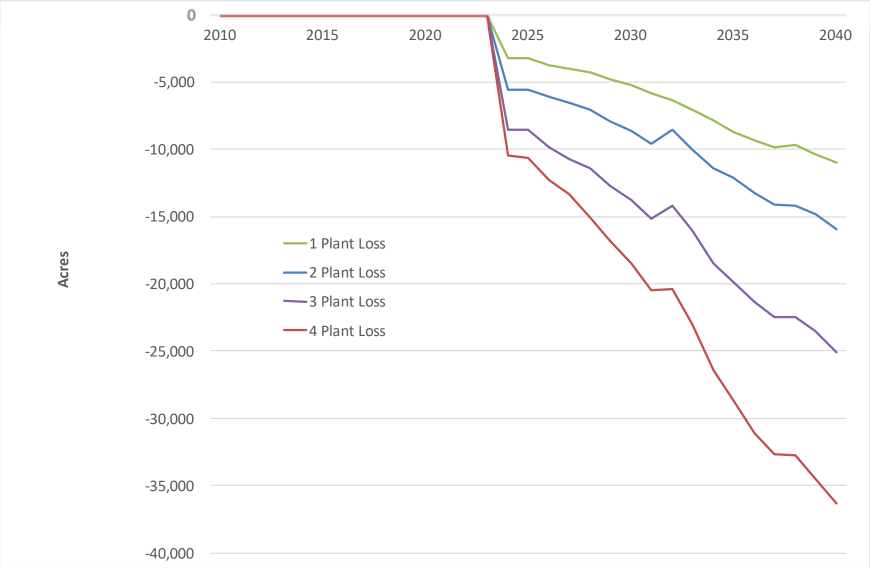
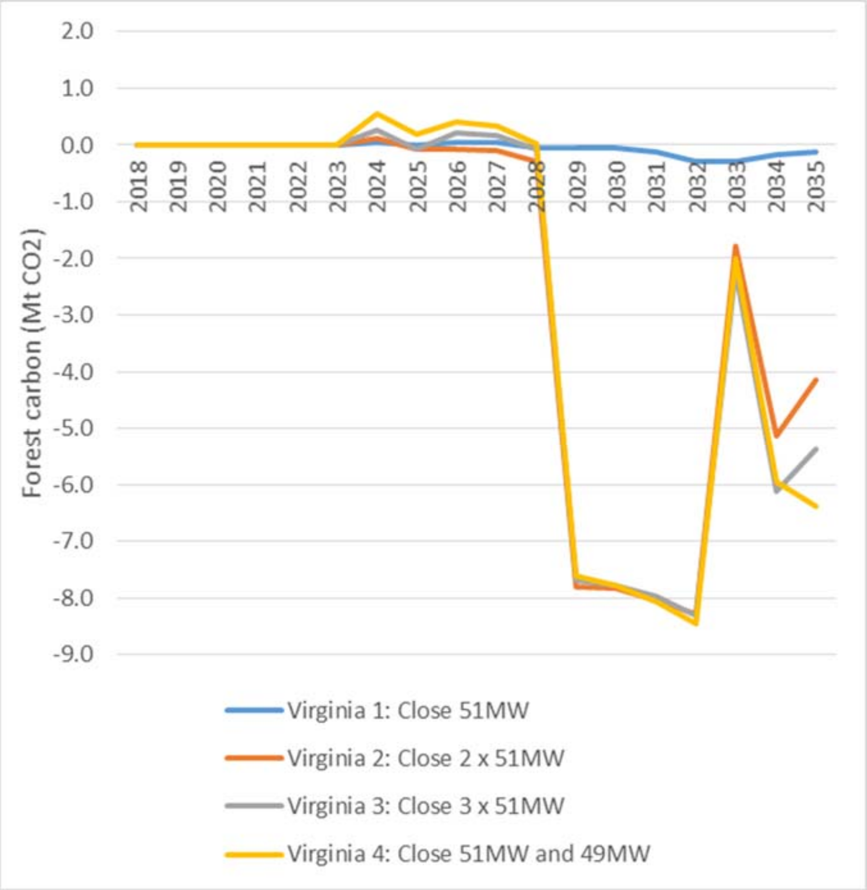


Figure 6.6. Cumulative carbon stock change from baseline for Virginia scenarios, 2018 – 2035.



quick comparison across scenarios. Table 6.12 shows power plant and terrestrial emissions by scenario (tCO$_2$/yr), and by MWh of electricity production. Scenario #4 yields the largest impact on total emissions, but lower than scenarios #2 and #3 on an MWh basis.

To understand the impact of any scenario, annual emissions from biomass need to be compared to annual emissions from the reference condition using fossil fuels to produce the same amount of energy (483,750 MWh/yr to 1,745,537 MWh/yr). Net change in projected forest carbon emissions were compared to the 10-year average in-state coal and natural gas carbon emissions (Table 6.1) to illustrate possible offsets by modeled scenario assuming lost biopower generation (scenarios #1-4) would be replaced with fossil fuel. Actual offsets would require comparison to future fossil fuel emissions. Positive values indicate a net displacement of fossil fuel emissions, or decline in total emissions; negative values indicate a net increase in total emissions as a result of the scenario. Results in Table 6.12 illustrate that total carbon emissions would be less if biopower was retained than compared to the 10-year average fossil fuel replacement for all but scenario #2 with natural gas (-0.19 t CO$_2$/MWh). In other words, replacing that amount of lost biopower with coal would result in a net increase in emissions of between 0.47 t CO$_2$/MWh and 0.93 t CO$_2$/MWh, and for natural gas between -0.19 t CO2/MWh and 0.27 t CO$_2$/MWh.

Table 6.12. Average annual net change in landscape forest carbon emissions, 2023-2035.

Scenario (% residues utilized)	Feedstock consumption (bdt/yr)	Power plant emissions (tonnes CO2/yr)	Energy generation (MWh/yr)	Virginia live tree emissions (tCO2/yr)	Virginia live tree energy intensity (tCO2/MWh)	Net fossil fuel energy intensity displacement (tCO2/MWh)*	
						Coal	**NG**
Virginia 1 (90%)	-325,000	-595,400	-438,750	-72,925	0.18	0.93	0.27
Virginia 2 (90%)	-650,000	-1,190,800	-877,500	-510,101	0.64	0.47	-0.19
Virginia 3 (90%)	-975,000	-1,786,200	-1,316,250	-531,173	0.44	0.67	0.01
Virginia 4 (90%)	-1,292,990	-2,368,758	-1,745,537	-550,682	0.35	0.76	0.10

*Net change in average annual emissions comparing bioenergy scenarios (years 2019-2035) to coal and natural gas (NG) (years 2006-2015). Positive values indicate a net decrease in total emissions; negative values indicate a net increase in total emissions. Observed average annual energy intensity of coal (0.96 tCO2/MWh) and natural gas (0.44 tCO2/MWh) are documented in Table 6.1.

6.6. Conclusion

The impact of a change in bioenergy capacity in Virginia is influenced by the proportion of logging residues that goes unutilized when decommissioning bioenergy facilities. SRTS model runs project a decrease in pine sawtimber prices across all scenarios, but little change in inventory or harvest removals across species, which is robust across scenarios suggesting that trends are a function of larger resource and market dynamics, and have less to do with the operation or decommissioning of bioenergy facilities in Virginia. The loss of bioenergy facilities does have an effect on forest acreage and land use; a loss in capacity is associated with a decline in forest area relative to the base case. As reported, changes are projected to have direct effects on landscape forest carbon, but the total GHG implications of changes in energy systems requires that net forest emissions be compared against a reference condition in which fossil fuels or other generation technologies are used. Projected forest emissions were compared to the 10-year in-state coal and natural gas emissions (2006-2015) to illustrate possible carbon offsets by modeled scenario. But comparison to future fossil fuel emissions was beyond the scope of this analysis and remains an important area for further research.

6.7. References

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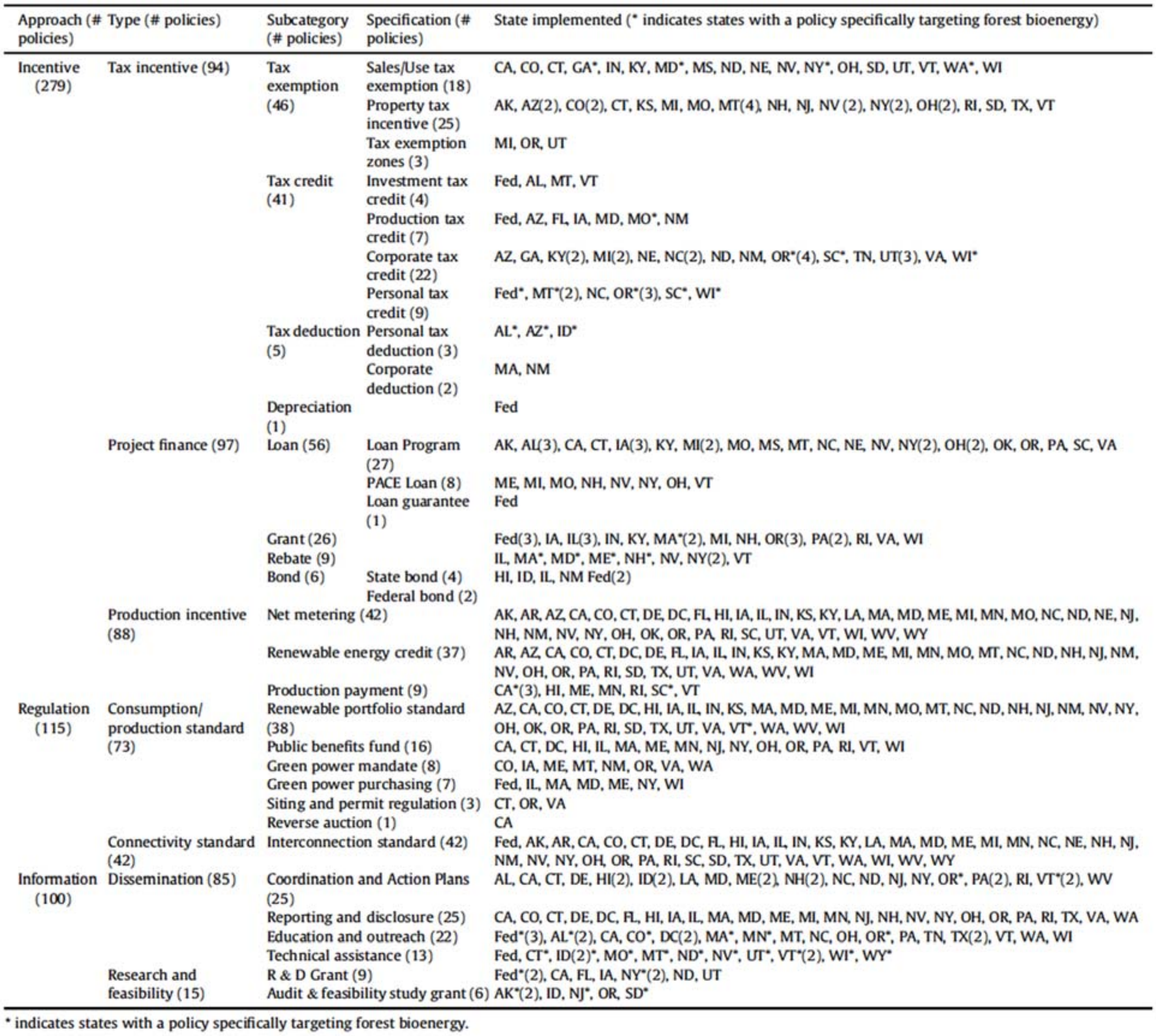
6.8. Appendix A:

Ebers et al. (2016) Classification of State’s Policy Approaches for Forest Biomass Production.



Approach (# policies)	Type (# policies)	Subcategory (# policies)	Specification (# policies)	State implemented (* indicates states with a policy specifically targeting forest bioenergy)
Incentive (279)	Tax incentive (94)	Tax exemption (46)	Sales/Use tax exemption (18)	CA, CO, CT, GA*, IN, KY, MD*, MS, ND, NE, NV, NY*, OH, SD, UT, VT, WA*, WI
			Property tax incentive (25)	AK, AZ(2), CO(2), CT, KS, MI, MO, MT(4), NH, NJ, NV (2), NY(2), OH(2), RI, SD, TX, VT
			Tax exemption zones (3)	MI, OR, UT
		Tax credit (41)	Investment tax credit (4)	Fed, AL, MT, VT
			Production tax credit (7)	Fed, AZ, FL, IA, MD, MO*, NM
			Corporate tax credit (22)	AZ, GA, KY(2), MI(2), NE, NC(2), ND, NM, OR*(4), SC*, TN, UT(3), VA, WI*
			Personal tax credit (9)	Fed*, MT*(2), NC, OR*(3), SC*, WI*
		Tax deduction (5)	Personal tax deduction (3)	AL*, AZ*, ID*
			Corporate deduction (2)	MA, NM
		Depreciation (1)		Fed
	Project finance (97)	Loan (56)	Loan Program (27)	AK, AL(3), CA, CT, IA(3), KY, MI(2), MO, MS, MT, NC, NE, NV, NY(2), OH(2), OK, OR, PA, SC, VA
			PACE Loan (8)	ME, MI, MO, NH, NV, NY, OH, VT
			Loan guarantee (1)	Fed
		Grant (26)		Fed(3), IA, IL(3), IN, KY, MA*(2), MI, NH, OR(3), PA(2), RI, VA, WI
		Rebate (9)		IL, MA*, MD*, ME*, NH*, NV, NY(2), VT
		Bond (6)	State bond (4)	HI, ID, IL, NM Fed(2)
			Federal bond (2)	
	Production incentive (88)	Net metering (42)		AK, AR, AZ, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, NC, ND, NE, NJ, NH, NM, NV, NY, OH, OK, OR, PA, RI, SC, UT, VA, VT, WI, WV, WY
		Renewable energy credit (37)		AR, AZ, CA, CO, CT, DC, DE, FL, IA, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, OH, OR, PA, RI, SD, TX, UT, VA, WA, WV, WI
		Production payment (9)		CA*(3), HI, ME, MN, RI, SC*, VT
Regulation (115)	Consumption/ production standard (73)	Renewable portfolio standard (38)		AZ, CA, CO, CT, DE, DC, HI, IA, IL, IN, KS, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, NY, OH, OK, OR, PA, RI, SD, TX, UT, VA, VT*, WA, WV, WI
		Public benefits fund (16)		CA, CT, DC, HI, IL, MA, ME, MN, NJ, NY, OH, OR, PA, RI, VT, WI
		Green power mandate (8)		CO, IA, ME, MT, NM, OR, VA, WA
		Green power purchasing (7)		Fed, IL, MA, MD, ME, NY, WI
		Siting and permit regulation (3)		CT, OR, VA
		Reverse auction (1)		CA
	Connectivity standard (42)	Interconnection standard (42)		Fed, AK, AR, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, NC, NE, NH, NJ, NM, NV, NY, OH, OR, PA, RI, SC, SD, TX, UT, VA, VT, WA, WI, WV, WY
Information (100)	Dissemination (85)	Coordination and Action Plans (25)		AL, CA, CT, DE, HI(2), ID(2), LA, MD, ME(2), NH(2), NC, ND, NJ, NY, OR*, PA(2), RI, VT*(2), WV
		Reporting and disclosure (25)		CA, CO, CT, DE, DC, FL, HI, IA, IL, MA, MD, ME, MI, MN, NJ, NH, NV, NY, OH, OR, PA, RI, TX, VA, WA
		Education and outreach (22)		Fed*(3), AL*(2), CA, CO*, DC(2), MA*, MN*, MT, NC, OH, OR*, PA, TN, TX(2), VT, WA, WI
		Technical assistance (13)		Fed, CT*, ID(2)*, MO*, MT*, ND*, NV*, UT*, VT*(2), WI*, WY*
	Research and feasibility (15)	R & D Grant (9)		Fed*(2), CA, FL, IA, NY*(2), ND, UT
		Audit & feasibility study grant (6)		AK*(2), ID, NJ*, OR, SD*

* indicates states with a policy specifically targeting forest bioenergy.

7. Washington

7.1 Executive Summary

The impact of new bioenergy production on carbon emissions in Washington is a function of existing energy production and consumption, forest growth and respiration, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to establish the reference baseline condition for Washington. Net carbon emissions from adding new electricity generation and pellet production using forest feedstocks is estimated from 2014 to 2035.

Model Parameters and Inputs

The Land Use and Resource Allocation (LURA) model is a forest products market projection system, solving for a recursive market equilibrium while accounting for the spatial detail associated with national forest resource base and forest products manufacturing base over time (Latta et al. 2018). The supply side of the model includes over 150,000 USDA Forest Service Forest Inventory and Analysis (FIA) forestland plots across the conterminous United States. Spatially disaggregated future supply is based on empirical yield functions for log volume, biomass and carbon. Demand data is based on a spatial database of over 2,500 forest product manufacturing facilities representing 11 intermediate and 13 final solid and pulpwood product categories.

The carbon emissions analyzed here are a function of landscape live-tree carbon and power plant emissions from the combustion of biomass for energy generation. Landscape carbon is based on (1) forest growth and respiration (i.e., forest structure is a function of change in age class over time, decay, mortality), (2) removals (e.g., harvests, timber stand improvement and restoration projects), and (3) fire, disturbance (e.g. hurricanes), insects, and diseases infestations. The location of carbon emissions is further influenced by forest products market dynamics driving competition and subsequent feedstock purchasing behavior. This dynamic will affect the location and intensity of forest harvesting, which affects subsequent forest growth and respiration, and probability of wildfire occurrence.

In consultation with Washington forestry and regulatory agencies, the six scenarios set out below were selected to model net change in carbon emissions from using forest feedstocks for energy production. Electricity generation is modeled for scenarios one through six varying facility size, number, and location. Each new facility is assumed to begin operations in 2019 collocated with existing or recently closed facilities. Feedstocks are constrained to biomass from logging residues in three of the scenarios; the allocation of sawlogs, pulpwood, and biomass is dictated by market dynamics in the other three scenarios. Logging residue utilization is capped at 60% of available limbs, tops or defect resulting from forest harvesting operations reflecting the proportion available in piles.

Washington modeled scenarios of potential facility location, size, and feedstock.

Scenario	Forks	Raymond	Cle Elum	Everett	Key Assumptions
Washington 1	5 MW	5 MW	5 MW		Logging residues only
Washington 2	5 MW	5 MW	5 MW		
Washington 3	5 MW				
Washington 4		5 MW			Logging residues only
Washington 5			5 MW		Logging residues only
Washington 6				50 MW	

We do not assume that forest biomass is carbon neutral. Rather, forest carbon is accounted for in real-time. A net increase in GHG emissions occurs when forest carbon storage in a bioenergy scenario is lower than that of the baseline. Alternatively, a net decrease in GHG emissions occurs when there is more forest carbon stored in the bioenergy scenario than in the baseline. Forest carbon totals are aggregated from live tree, dead tree, understory, down dead, and forest floor pools. Emissions are expressed as an average annual net change in landscape live-tree carbon from 2019 when the simulated facilities come online through 2035, and where applicable on an average annual MWh basis for electricity production. Net change is measured from the 2019 to 2035 baseline average values.

As the table below notes, compared to the baseline, the residual-only scenarios (#1,4,5) yielded among the lowest average annual net emissions over the 17-year horizon. Scenario #1 with three new 5 MW biomass electricity facilities dispersed throughout the state was about 19% of scenario #2 in-state emissions with the same facilities but where biomass feedstocks were not constrained to logging residuals. The difference between scenarios #3 and either #4 or #5 are greater, with and without logging residuals but only when looking at total in-state and out-of-state emissions; in-state emissions are nearly identical. By constraining feedstock supply to only logging residuals, scenarios #4 and #5 provide an additional revenue stream increasing in-state harvest that has a compensating reduction in out-of-state harvests. The reliance on roundwood in scenario #3 yields a similar increase in in-state harvest but as that harvest competes with traditional forest products uses it leads to a reduction in in-state production and a compensating increase in out-of-state production. The degree to which logging residues changes the emissions profile is based in large part on the degree to which the facility size is scaled appropriately to nearby wood products manufacturing and thus timber harvesting.

The influence of facility size is most apparent in scenario #6 where average annual live-tree emissions in Washington were 55,008 t CO_2 or 0.21 t CO_2/MWh. Emissions occurring outside Washington from shifts in production caused by the Everett 50 MW facility were fairly substantive given the relatively small change in biomass demand, which is possibly due to the importance of pulp and paper in the state's forest economy. Dynamic forest product markets are causing ripple effects in competing industries, which changes the distribution of logging activity of the price industries are willing to pay for sawlogs, which drives the availability of biomass. The impact on carbon emissions is negligible for all but scenario #6.

Average annual net change in landscape live tree carbon emissions, 2019-2035.

Scenario	Feedstock consumption (t/yr)	Power plant emissions (tonnes CO2/yr)	Energy generation (MWh/yr)	Total live tree emissions (tCO2/yr)	Minnesota live tree emissions (tCO2/yr)	Minnesota live tree energy intensity (tCO2/MWh)	Net fossil fuel energy intensity displacement (tCO2/MWh)*	
							Coal	NG
Washington 1	98,550	180,544	78,840	-824	2,239	0.03	1.04	0.42
Washington 2	98,550	180,544	78,840	17,036	12,047	0.15	0.92	0.30
Washington 3	32,850	60,181	26,280	7,654	1,916	0.07	1.00	0.38
Washington 4	32,850	60,181	26,280	-404	1,827	0.07	1.00	0.38
Washington 5	32,850	60,181	26,280	-1,204	1,749	0.07	1.00	0.38
Washington 6	328,500	601,812	262,800	64,135	55,008	0.21	0.86	0.24

*Net change in average annual emissions comparing bioenergy scenarios (years 2019-2035) to coal and natural gas (NG) (years 2006-2015). Positive values indicate a net decrease in total emissions; negative values indicate a net increase in total emissions.

To understand the impact of any scenario, annual emissions from biomass need to be compared to annual emissions from the reference condition using fossil fuels to produce the same amount of energy (26,280 MWh/yr to 262,800 MWh/yr). Net change in projected forest carbon emissions were compared to the 10-year average in-state coal and natural gas carbon emissions to illustrate possible offsets by modeled scenario. Actual offsets would require comparison to future fossil fuel emissions. Positive values indicate a net displacement of fossil fuel emissions, or decline in total emissions; negative values indicate a net increase in total emissions as a result of the scenario. Results illustrate that total carbon emissions would be less for each biopower scenario when compared to the 10-year average fossil fuel alternative. The largest decline in emissions are observed comparing to coal power and range from 0.86 t CO2/MWh (scenario #6) up to 1.04 t CO2/MWh (scenario #1).

Conclusion

The impact of new bioenergy production on carbon emissions in Washington is most influenced by whether or not feedstocks are constrained to logging residues, at least as the scales modeled. The residual-only scenarios yielded the lowest average annual net emissions over the 17-year horizon. Net annual emissions are negligible or even negative for out-of-state impacts for all but scenario #6, suggesting that the scale of modeled production has little impact on statewide GHG profiles. Comparing results to the baseline condition from 2019 to 2035 also suggests that net emissions are more likely a function of changes in national resource conditions and market dynamics than with the operation of bioenergy facilities in Washington. As reported, changes are projected to have direct effects on landscape forest carbon, but the total GHG implications of changes in energy systems requires that net forest emissions be compared against a reference condition in which fossil fuels or other generation technologies are used. Projected forest emissions were compared to the 10-year in-state coal and natural gas emissions (2006-2015) to illustrate possible carbon offsets by modeled scenario. But comparison to future fossil fuel emissions was beyond the scope of this analysis and remains an important area for further research.

7.2. Introduction

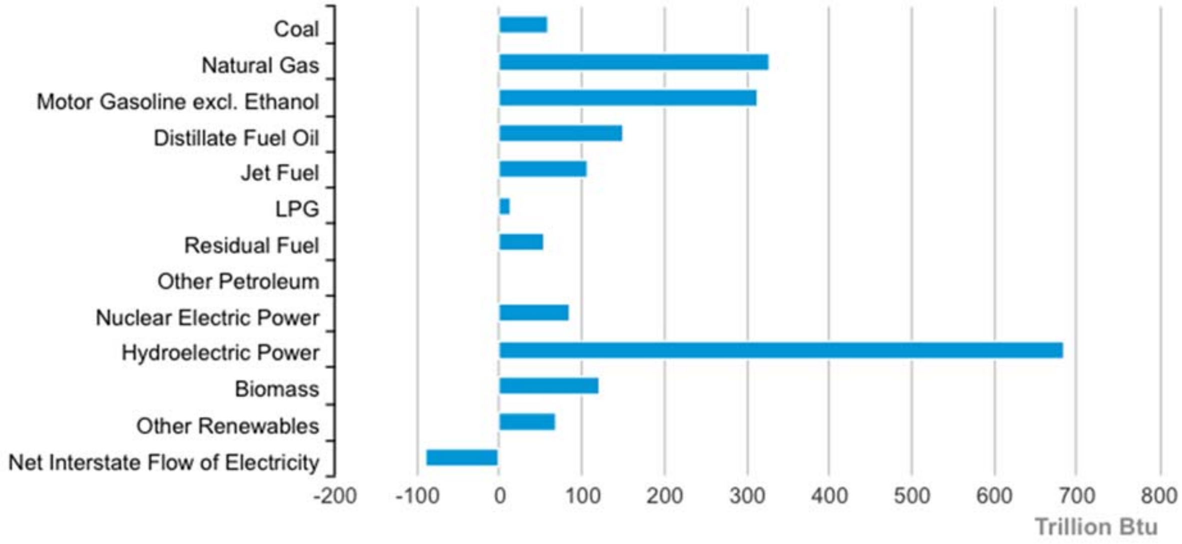
The impact of new bioenergy production on carbon emissions in Washington is a function of existing energy production and consumption, forest growth and respiration, and the distribution of forest products industries and market competition. Energy profiles and changes in forest inventories by ownership from 2006 to 2015 are presented to establish the reference baseline condition for Washington. Net carbon emissions from adding new electricity generation and pellet production using forest feedstocks is estimated from 2014 to 2035. These data may be used for establishing criteria for incorporating forest feedstocks into state and national greenhouse gas (GHG) accounting frameworks.

7.3. Washington Energy Profile

7.3.1. Energy Production and Consumption

States' energy profiles are comprised of energy production, energy consumption, and energy imports, which are a function of price and availability.[44] In 2015, the most recent year comprehensive US Energy Information Agency (EIA) data is available,[45] Washington's primary energy production was limited to nuclear electricity power (85.3 trillion British Thermal Units (Btu)) and renewable energy (849.4 trillion Btu), namely hydroelectric power, biomass, and other renewables. The state had no primary production of coal, natural gas, crude oil, or biofuels (EIA 2017a, Table P2). Washington consumed 1,988.4 trillion Btu of energy in 2015 (Figure 7.1.), of which 1,053.7 trillion Btu was produced from imports of primary energy production and their derivatives from other states (EIA 2017a, Table P3). In 2015, using these imports and its own production, Washington exported 90.5 trillion Btu in the form of electricity to other states (EIA 2017b, Table C1).

Figure 7.1. Washington Energy Consumption Estimates, 2015 (Source: EIA 2017c).



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[44] Since energy prices are fairly volatile, this report does not include price information. Historic (1970-2015) energy price information is available at: https://www.eia.gov/state/seds/sep_prices/notes/pr_print.pdf.

[45] As of October 2017.

7.3.2. Electricity Production and Consumption

In 2015, Washington produced 109.3 million megawatt hours (MWh) of electricity in (EIA 2016a), which was 1 percent more than produced in 2006 (Table 7.1). Fossil fuels, natural gas (11.9%) and coal (4.6%), and nuclear (7.5%) produced less than a quarter of the state's power in 2015. The majority of electricity generated within the state was from hydroelectric (67.2%), with other renewables, such as wind (6.5%), and wood and wood derived fuels adding 6.5 and 1.5 percent, respectively (EIA 2016a). Total annual emissions across all energy sources averaged 0.11 tCO2/MWh. Coal derived energy produced the majority of emissions averaging 1.07 tCO2/MWh per year.

Table 7.1. Electricity Generation and Emissions for Washington, by Energy Source* (Source: EIA 2016a).

Year	Coal	Natural Gas	Nuclear	Hydro	Wind	Wood and Wood Derived Fuels	Total**	CO2 Emissions (Mt CO2)	Energy Intensity (tCO2/MWh)
	Million megawatt hours								
2006	6.4	7.5	9.3	82.0	1.0	1.3	108.2	10.5	0.10
2007	8.6	7.3	8.1	78.8	2.4	1.1	107.0	12.8	0.12
2008	8.8	9.8	9.3	77.6	3.7	1.1	110.8	13.7	0.12
2009	7.5	12.0	6.6	72.9	3.6	1.3	104.5	13.5	0.13
2010	8.5	10.4	9.2	68.3	4.7	1.7	103.5	14.0	0.14
2011	5.2	4.8	4.8	91.8	6.3	1.6	115.3	8.2	0.07
2012	3.8	5.4	9.3	89.5	6.6	1.4	116.8	7.0	0.06
2013	6.7	11.4	8.5	78.2	7.0	1.5	114.2	12.5	0.11
2014	6.7	11.1	9.5	79.5	7.3	1.5	116.3	12.5	0.11
2015	5.1	13.0	8.2	73.4	7.1	1.7	109.3	11.6	0.11
	Energy intensity (tCO2/MWh)								
10-yr avg	1.07	0.45	0.0	0.0	0.0	0.0	0.11	--	--

* Table omits energy sources that produced an average of 1 million MWh or less per year during these 10 years. This included "Other Gases" (produced an average of 0.3 million MWh/year), and "Other Biomass" (averaged: 0.2 million MWh/year), "Other" sources (averaged: 0.1 million MWh/year), and Petroleum", "Pumped Storage", and "Solar Thermal and Photovoltaic" (averaged less than 0.1 million MWh per year).

** Row totals may not add up due to rounding and sources omitted in accordance with previous note.

Washington's electricity generators and combined heat and power (CHP) generators produced 109.3 million MWh of electricity in 2015. Electricity generators produced the majority of this (106.7 million MWh; 89.8% of all generation), of which electricity utilities generated 93.7 million MWh and independent power producers generated 13 million MWh (EIA 2016a). CHP facilities generated only 2.5 million MWh of the state's electricity – industrial power CHPs generated 1.5 million MWh, and electricity and commercial power CHPs generated 1 million MWh and less than 0.1 million MWh, respectively (EIA 2016a).

Washington consumed 90.1 million MWh of electricity and exported 19.2 million MWh in 2015 (EIA 2016a; EIA 2016b). The largest shares of electricity used within the state was by the residential (37.8%) and commercial (32.5%) sectors. The industrial sector consumed 29.7 percent and the transportation sector consumed less than 0.1 percent of this electricity (EIA 2016b).

7.3.3. Electricity from Forest Biomass Resources. In 2015, net electricity generation from forest biomass, using EIA's Wood and Wood Derived Fuel definition,[46] provided nearly 1.7 million MWh (1.5%) of Washington's electricity in 2015 (Table 7.2) – more than any other sources besides coal, natural gas, nuclear, hydroelectric and wind (Table 7.1) (EIA 2016a). Forest biomass-based electricity generation increased 32.1 percent from 2006 to 2015, with more than 81 percent of that electricity in 2015 produced by industrial power CHP facilities (EIA 2016a).

Table 7.2. Washington Net Generation from "Wood and Wood Derived Fuels" by Type of Producer and Year in thousand megawatt hours (Source: EIA 2016a).

Year	Combined Heat and Power			Electricity Generators		Total
	Industrial Power	Commercial Power	Electricity Power	Independent Power Producers	Electricity Utilities	
2006	681	0	0	0	600.2	**1,281.2**
2007	549.2	0	0	0	567.2	**1,116.4**
2008	735.1	0	177.5	0	200.5	**1,113.1**
2019	946.6	0	176.6	0	182.9	**1,305.2**
2010	1,168.9	0	0	0	507	**1,675.9**
2011	1,139.6	0	0	0	442.6	**1,582.3**
2012	1,165.9	0	0	0	208.9	**1,374.8**
2013	1,238.6	0	0	0	294.1	**1,532.7**
2014	1,267.4	0	0	0	259.1	**1,526.6**
2015	1,372	0	0	0	320.2	**1,692.3**

7.3.4. Biomass Thermal Heat Generation

In 2015, heat from wood, wood-derived fuels, and biomass waste[47] was used in Washington's residential, commercial, and industrial sectors (Table 7.3.) (EIA 2017b). EIA estimated that thermal uses (89.3 trillion Btu) of these materials in the state were 10.8 times greater than the 8.3 trillion Btu from the use of this biomass to produce electricity (EIA 2017b, Tables CT3 and CT8),[48] and that Washington's thermal use of forest biomass decreased 5.9 percent from 2006 to 2015.

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[46] EIA (2017d) defines Wood and Wood-Derived Fuels as "Wood/Wood Waste Solids (including paper pellets, railroad ties, utility poles, wood chips, bark, and wood waste solids)[,] Wood Waste Liquids (excluding Black Liquor but including red liquor, sludge wood, spent sulfite liquor, and other wood-based liquids)[, and] Black Liquor. *Note:* EIA's (2017d) "Other Biomass" category includes other types of biomass, such as "Agricultural By-Products[,] Municipal Solid Waste[,] Other Biomass Gas (including digester gas, methane, and other biomass gases) [,] Other Biomass Liquids[,] Other Biomass Solids[,] Landfill Gas[, and] Sludge Waste. However, since this report's modeling focuses on forest biomass and its derivatives, this report focuses exclusively on EIA's Wood and Wood-Derived Fuels.

[47] EIA (2017d) defines biomass waste as "[o]rganic non-fossil material of biological origin that is a byproduct or a discarded product. Biomass waste includes municipal solid waste from biogenic sources, landfill gas, sludge waste, agricultural crop byproducts, straw, and other biomass solids, liquids, and gases; but excludes wood and wood-derived fuels (including black liquor), biofuels feedstock, biodiesel, and fuel ethanol. Note: EIA biomass waste data also include energy crops grown specifically for energy production, which would not normally constitute waste." *Note:* This definition differs from EIA's definition of "Other Biomass" – see previous footnote.

[48] "The electric power sector comprises electricity-only and combined-heat-and-power (CHP) plants ... whose primary business is to sell electricity, or electricity and heat, to the public" (EIA 2017b, 441).

Table 7.3. Washington Energy Consumption Estimates for Thermal and Electricity Power from "Wood, Wood-Derived Fuel, and Biomass Waste" by Year and Type of Producer in trillion Btu (Source: EIA 2017b, Tables CT2, CT3, CT4, CT5, CT6, CT8).

Year	Thermal Power (trillion Btu)				Electricity Power (trillion Btu)	Total Consumption (trillion Btu)
	Residential Sector (thousand cords*)	Commercial Sector	Industrial Sector	Thermal Total		
2006	10.1 (503)	1.7	81.1	92.9	10.9	103.7
2007	11.1 (556)	1.8	54.9	67.8	11.2	79.1
2008	12.4 (622)	1.9	55.3	69.6	7.7	77.3
2009	17.5 (877)	2.5	56.6	76.6	7.8	84.3
2010	15.3 (766)	2.4	69.5	87.3	10.3	97.6
2011	15.7 (783)	2.4	69.1	87.1	9.2	96.3
2012	14.6 (731)	2.1	72.4	89.1	6.3	95.4
2013	20.2 (1,010)	2.5	70.3	93	7.7	100.6
2014	20.6 (1,028)	2.6	70.7	93.9	7.8	101.7
2015	15.3 (766)	2.8	71.2	89.3	8.3	97.6

* EIA only estimated cord wood usage for this sector (EIA 2017b, Table CT4).

7.3.5. State Energy Choices

State energy policy choices are based upon goals like increasing economic development, energy security, energy reliability (e.g., base and peak load capacity), stabilizing energy prices, and reducing air pollution and GHG emissions. These policies influence states' energy mixes and can cause energy producers and consumers to favor one or more energy sources over others. As Ebers et al. (2016, 67) noted as of "September 2013, federal and state governments had created 494 policies to support production of electricity and heat from forest biomass." Building on Becker et al. (2011), Ebers et al. (2016, 67) developed "a four-tier classification structure to categorize policy instruments based on: approach (incentive, regulation, information), type (e.g. tax incentive), subcategory (e.g. tax exemption), and specification (e.g. sales tax exemption)" (see Appendix A).

In Washington, the most common policy approach focused on stimulating forest biomass energy were sales/use tax exemption.[49] Other incentives specific to renewable energy, but not limited to electricity or heat produced from forest biomass, included renewable energy credits, renewable portfolio standard, green power mandates, interconnection standards, and education and outreach (Ebers et al. 2016).

7.3.6. Biomass Energy CO_2 and Other Emissions

State energy choices regarding fossil fuels and renewables to produce heat and electricity have CO_2 and other emission implications. Emissions from biomass energy generation vary greatly depending on the feedstock source, location, conversion efficiency, and other factors. Combining heat with electricity production significantly increases efficiency over standalone electricity production and reduces GHG emissions per unit of energy generation, while dried forest biomass (e.g., pellets and dried wood chips) will provides higher conversion efficiencies than green wood chips (Schlamadinger et al. 1997). Feedstock proximity, which affects greenhouse gas emissions from biomass transportation also impacts emissions, with biomass facilities price- and volume-constrained based on feedstock availability and competition from other biomass users (Schlamadinger et al. 1997, Galik et al. 2009).

In 2015, electricity production from *all sources* in Washington produced an estimated 11.6 million metric tons of CO_2, 11,546 metric tons of SO_2, and 13,931 metric tons of NO_X (EIA 2016c). Of these emissions, wood and wood-derived fuels produced 72.9 percent of the state's SO_2 emissions, and 26.2 percent of its

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[49] The policy approaches reported in this paragraph use Ebers et al.'s (2016, 70) policy names/terminology.

NO_X emissions (Table 7.4.) (EIA 2016c). Because the EIA follows current international convention and assumes that CO_2 "released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions" (EIA 2011), *none* of Washington's estimated CO_2 electricity emissions include CO_2 emissions from biomass.[50]

Table 7.4. Washington Estimated Emission from "Wood and Wood-Derived Fuel" by Type of Producer in metric tons (Source: EIA 2016c).

Year	Emission	Electric Utility	Independent Power Producers		Commercial		Industrial		Total
			Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	Non-Cogeneration	Cogeneration	
2006	SO_2	66	0	0	0	0	0	7,219	**7,285**
	NO_x	295	0	0	0	0	0	3,775	**4,070**
2007	SO_2	71	0	0	0	0	0	6,928	**6,999**
	NO_x	400	0	0	0	0	0	2,210	**2,610**
2008	SO_2	39	0	21	0	0	0	6,935	**6,995**
	NO_x	220	0	63	0	0	0	2,120	**2,403**
2009	SO_2	35	0	24	0	0	0	8,343	**8,402**
	NO_x	199	0	72	0	0	0	2,881	**3,152**
2010	SO_2	86	0	0	0	0	0	10,675	**10,761**
	NO_x	406	0	0	0	0	0	4,046	**4,452**
2011	SO_2	56	0	0	0	0	0	15,862	**15,918**
	NO_x	317	0	0	0	0	0	3,836	**4,153**
2012	SO_2	47	0	0	0	0	1,695	16,498	**18,240**
	NO_x	264	0	0	0	0	402	2,735	**3,401**
2103	SO_2	62	0	0	0	0	1,636	7,514	**9,212**
	NO_x	545	0	0	0	0	508	2,903	**3,956**
2014	SO_2	59	0	0	0	0	0	8,872	**8,931**
	NO_x	521	0	0	0	0	0	3,148	**3,669**
2015	SO_2	67	0	0	0	0	0	8,353	**8,420**
	NO_x	594	0	0	0	0	0	3,057	**3,651**

While international convention and the EIA assume that "the CO_2 released from biofuel or bioenergy combustion … [is] fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy," (EIA 2011, 60) from a landscape perspective forests can be a CO_2 sink, CO_2 source, or carbon neutral (Malmsheimer et al. 2008). Forests are a CO_2 sink when live and dead vegetation, litter, and soil sequester more carbon than emitted, and forests are a carbon source when these emissions exceed sequestration rates (Wear and Coulston 2015). Management actions such as timber harvesting, or natural disturbances like wildfires affecting the CO_2 balance determines the extent to which a forest is a net sink or source of CO_2 to the atmosphere (Woodall et al. 2015). Carbon is also sequestered in harvested wood products, such as lumber and paper, which affects the CO_2 balance (EIA 2011; Malmsheimer et al. 2008). At the end of a products' useful life, the carbon is either released

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[50] As EIA notes, "According to current international convention, CO_2 released through the combustion of energy or fuel derived from plants (bioenergy or biofuels) is excluded from reported energy-related emissions. The related fossil fuel emissions from the transportation and processing of the biological feedstocks are captured within overall energy sector emissions, but currently they are not allocated to the biofuels. Additionally, the CO_2 released from biofuel or bioenergy combustion is assumed to be fully accounted for by the uptake of carbon during the growth of the feedstock used to produce the biofuels or bioenergy. However, analysts have debated whether the increased use of biomass energy may result in a loss of terrestrial carbon stocks and foregone future sequestration by natural vegetation. The initial loss of carbon stocks in natural vegetation cleared to grow biomass feedstocks and the foregone future removal of CO_2 are not captured in energy sector emissions. To capture the potential net emissions, the international convention for GHG inventories is to report the net carbon flux from land use change (such as when forests are converted to cropland to grow feedstocks) in the Land Use category. Although accounting for land use emissions is more challenging than for most of the other emissions sources, emissions and sequestration associated with domestic U.S. land use change should in principle be accounted for in this chapter of the inventory report. However, from a global greenhouse gas emissions perspective, the key uncertainty regarding aggregate net biogenic emissions is indirect land use change that occurs abroad." (EIA 2011).

directly into the atmosphere through burning and energy combustion (Malmsheimer et al. 2011; Miner et al. 2014), or natural decomposition or decay in landfills (Skog 2008).[51]

While most forest-based carbon is eventually released into the atmosphere, forest products and forest biomass energy provide documented benefits. As Malmsheimer et al. (2011, S9) described, "[f]orest products used in place of energy intensive materials such as metals, concrete and plastics (a) reduce carbon emissions (because forest products require less fossil fuel-based energy to produce), (b) store carbon (for a length of time based on products' use and disposal), and (c) provide biomass residuals (i.e., waste wood) that can be substituted for fossil fuels to produce energy. [In addition,] [f]ossil fuel–produced energy releases carbon into the atmosphere that has resided in the Earth for millions of years; forest biomass–based energy uses far less of the carbon stored in the Earth thereby reducing the flow of fossil fuel–based carbon emissions to the atmosphere."

7.4. Forest Sector Profile

7.4.1. The Condition of the Forest Resource

As a lower value commodity relative to sawlogs and other forest products, the availability of biomass for energy generation often depends on traditional forest products markets to generate sufficient financial incentive to enable biomass removal (Oswalt et al. 2018; Miner et al. 2014). These markets depend in large part on the condition of a state's forest resource, species composition, and forest products manufacturing base

More than half (52.1%) of Washington is forested, and the number of acres has decreased slightly since 2011 (Table 7.5.) (Oswalt et al. 2014; 2018). More than 73 percent of the state's timberlands – forests producing or capable of producing industrial wood, and not withdrawn from timber utilization – have natural origins, as opposed to being planted (Oswalt et al. 2018).

Table 7.5. Washington Land Area, by Year, in thousands of acres (Sources: Oswalt et al. 2014; 2018 (Tables 1a)).

Year	**Total Land Area**	**Forestland***					**Woodland******	**Other Land**
		Total	**Timberland****		**Reserved*****	**Other**		
			Planted	**Natural Origin**				
2011	42,532	22,435	4,474	13,607	3,820	534	0	20,097
2017	42,532	22,174	4,775	13,018	3,820	560	165	20,192

* Forestland is defined as, "Land at least 120 feet (37 meters) wide and at least 1 acre (0.4 hectares) in size with at least 10 percent cover (or equivalent stocking) by live trees including land that formerly had such tree cover and that will be naturally or artificially regenerated. Trees are woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. The definition here includes all areas recently having such conditions and currently regenerating or capable of attaining such condition in the near future. Forest land also includes transition zones, such as areas between forest and nonforest lands that have at least 10 percent cover (or equivalent stocking) with live trees and forest areas adjacent to urban and built-up lands. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 120 feet (37 meters) wide or an acre in size. Forest land does not include land that is predominantly under agricultural or urban land use." (Oswalt et al. 2018, 2).

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[51] As Malmsheimer et al. (2011, S30), noted "Of the wood products that enter solid waste disposal sites, more than three quarters of the carbon in solid wood and almost one-half of the carbon in paper is never released to the atmosphere … . The carbon that is released during decay takes many years to reach the atmosphere. For example, the 23% of the solid wood that does decay has a half-life of 29 years. Skog (2008) found that when paper is landfilled, the nonlignin component (56%) decays, leaving the lignin component (44%) as a long-term store in the landfill … . This nondegradable fraction varies by grade, from approximately 10% for bleached chemical pulp fibers to 85% for mechanical pulp fibers (US EPA 2006)."

** Timberland is defined as, “Forest land that is producing or is capable of producing crops of industrial wood and not withdrawn from timber utilization by statute or administrative regulation. (Note: Areas qualifying as timberland are capable of producing in excess of 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.)” (U.S. Forest Service 2017a).

*** Woodland is defined as, “a class of land which consists predominantly of stands of sparse woodland species such as juniper, pinyon juniper, mesquite and small stature hardwood species and are found in the arid to semiarid regions of the interior western United States. These areas must span more than 1 acre (0.4 hectares, have sparse trees capable of achieving 16.4 feet (5 meters) in height in situ, and a tree canopy cover of 5 to 10 percent. When combined with shrubs and bushes these areas may achieve overall cover greater than 10 percent woody vegetation. Trees are defined as woody plants having a more or less erect perennial stem(s) capable of achieving at least 3 inches (7.6 cm) in diameter at breast height, or 5 inches (12.7 cm) diameter at root collar, and a height of 16.4 feet (5 meters) at maturity in situ. These areas do not include land that is predominantly under agricultural or urban land use.” (Oswalt et al. 2018, 2).

**** Reserved Forestland is defined as, “Land permanently reserved from wood products utilization through statute or administrative designation. Examples include National Forest wilderness areas and National Parks and Monuments.” (U.S. Forest Service 2017a).

Softwoods constitute 91.8 percent of Washington’s timberland growing stock (Table 7.6.) (Oswalt et al. 2018). Most (76.8%) of the state’s estimated 1,873 million dry tons of above ground biomass is in the boles of live trees with a diameter at breast height of 5 or more inches, 12.9% in the tops and limbs and 3.5% in stumps (Oswalt et al. 2018). Saplings contain 2.1% of above ground biomass and sound dead biomass, which the U.S. Forest Service defines as salvageable dead trees, comprises 4.6% of all such biomass in the state (U.S. Forest Service 2017a).

Table 7.6. Washington Timberland (1) Growing Stock by Species Type, and (2) Above Ground Biomass by Tree Component, 2017 (Source: Oswalt et al. 2018 (Tables 17 and 38a)).

Growing Stock Volume ***(in million cubic feet)***			**Above Ground Biomass** ***(in million dry tons)***						
			Total Biomass	**Live Tree Biomass**					**Sound Dead Biomass**
				Greater than 5-inches DBH			**Sapling Biomass**	**Woodland Species**	
Total	**Softwood**	**Hardwood**		**Boles**	**Stumps**	**Tops/Limbs**			
68,356	62,736	5,619	1,873	1,438	66	242	39	1	87

Data may not add to totals because of rounding.

In 2017, net growth exceeded mortality and removals in Washington timberland by more than 1.5 billion cubic feet (Table 7.7.), and net growth decreased 1.4 percent from 2011 to 2017 (Oswalt et al. 2014; 2018). Almost 93 percent of net growth in 2017 occurred in softwoods (Table 7.7.).

Table 7.7. Washington Annual Growth, Removals, and Mortality of Growing Stock on Timberland by Species Type, 2017, in thousand cubic feet (Source: Oswalt et al. 2014; 2018 (Table 36)).

	All Species			**Softwoods**			**Hardwoods**		
	Net growth*	**Removals**	**Mortality**	**Net growth***	**Removals**	**Mortality**	**Net growth***	**Removals**	**Mortality**
2011	1,602,371	717,283	415,467	1,470,980	676,738	363,371	131,391	40,545	52,095
2017	1,580,265	805,344	656,671	1,465,772	767,893	566,124	114,493	37,452	90,547

* “[N]et annual growth [is t]he average annual net increase in the volume of trees during the period between inventories. Components include the increment in net volume of trees at the beginning of the specific year surviving to its end, plus the net volume of trees reaching the minimum size class during the year, minus the volume of trees that died during the year and minus the net volume of trees that became cull trees during the year” (Oswalt 2014, 33). Thus, net annual growth includes mortality, but does not include removals, so removals must be subtracted from net growth to calculate increases or decreases in growing stock *in the forest*.

Approximately 57.3 percent of Washington’s timberlands are managed by public entities. Federal agencies administer 44.2 percent of all timberlands, the State of Washington 11 percent, and counties and municipalities 2 percent (Table 7.8) (Oswalt et al. 2018). Industrial owners own 21.5 percent of Washington’s timberlands and non-industrial owners, also known as family forest owners, own 21.2 percent.

Table 7.8. Washington Timberland Area by Ownership, 2017, in thousands of acres (Source: Oswalt et al 2018 (Table 2)).

	Public					Private		Total
	Federal			State	County & Municipal	Industrial	Non-Industrial	
	National Forest	BLM	Other					
	8,331	55	1,415	2,449	453	4766	4,705	
Subtotals	9,802							
Totals	12,703					9,471		22,174

Data may not add to totals because of rounding.

7.4.2. The Forest Industry

The vast majority (94.5%) of timber products manufactured in Washington were produced from softwoods (Table 7.9.) (Source: Oswalt et al. 2014 (Table 39)). Private forests supplied the majority of softwood-based (67.4%) and hardwood-based (64.4%) feedstocks. Saw logs represented 63.8 percent (by volume) of all of the state's timber products. Pulpwood (24.7%) were the only other product category using more than 10 percent of in-state wood supply.

Table 7.9. Washington Volume of Industrial Timber Products by Ownership Class and Timber Product, 2011, in millions of cubic feet (Source: Source: Oswalt et al. 2014 (Table 39); Forest Service 2017b).

Ownership Class	Total	Saw Logs	Veneer Logs	Pulpwood	Composite Products	Residential Fuelwood*	Post-Poles-Pilings	Other Industrial
Softwoods								
National Forests	36,101	17,555	1,777	11,678	0	4,780	312	0
Other Public	196,643	132,991	10,974	43,883	0	5,657	3,096	42
Private	481,613	312,245	20,018	112,462	0	32,057	4,831	0
Softwoods Total	714,357	462,790	32,769	168,023	0	42,493	8,239	42
Hardwoods								
National Forests	1,070	1,070	1,070	1,070	0	1,070	0	0
Other Public	13,825	6,523	239	6,766	0	298	0	0
Private	26,910	12,883	999	11,341	0	1,687	0	0
Hardwoods Total	41,805	19,980	1,320	18,519	0	1,987	0	0
Total Softwoods and Hardwoods	756,162	482,770	34,088	186,542	0	44,480	8,239	42

Numbers in rows and columns may not add to totals due to rounding.

* Fuelwood includes industrial fuelwood from TPO mill surveys and residential firewood from Department of Energy estimates.

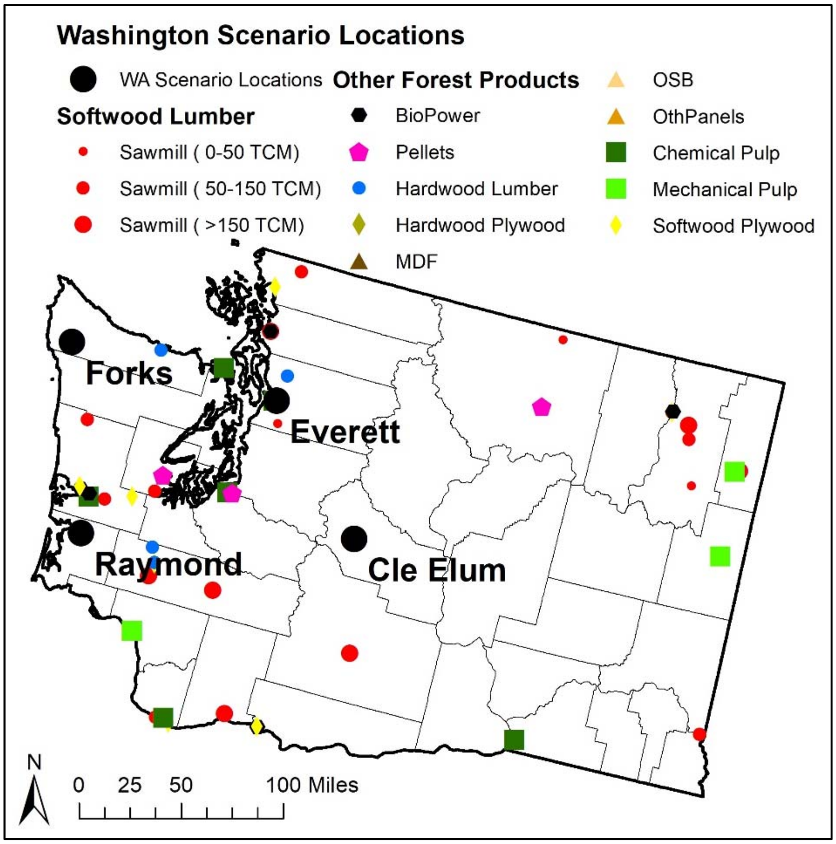
7.5. Forest CO_2 Modeling

7.5.1. Model Parameters and Inputs

The Land Use and Resource Allocation (LURA) model is a forest products market projection system, solving for a recursive market equilibrium while accounting for the spatial detail associated with national forest resource base and forest products manufacturing base over time (Latta et al. 2018). The supply side of the model includes over 150,000 USDA Forest Service Forest Inventory and Analysis (FIA) forestland plots across the conterminous United States. Spatially disaggregated future supply is based on empirical yield functions for log volume, biomass and carbon. Demand data is based on a spatial database of over 2,500 forest product manufacturing facilities representing 11 intermediate and 13 final solid and pulpwood product categories. The composition and distribution of those facilities in Washington are presented in Figure 7.2 and Table 7.10.

Transportation costs are derived from fuel prices and the locations of FIA plot from which a log is harvested and mill or port destination. Trade among mills in intermediate products such as sawmill residues or planer shavings is captured within the model formulation. The advantage of this modeling approach is that projections of forest harvest and carbon emissions incorporate changes in the local industrial makeup (new mills or products) directly allowing for evolving regional harvest-price-inventory relationships. LURA can be used to either meet an exogenous forest products demand level through optimal allocation of primary and secondary forest derived commodities, or allocate an exogenous harvest level across all forests and mills in the United States.

Figure 7.2. Washington Primary Wood-Using Mills and Bioenergy Expansion Scenario Locations, 2014 (Source: Latta et al. 2018).



Future forest product demand is an exogenous variable set using key macroeconomic and energy market drivers from the 2015 Annual Energy Outlook (AEO) reference case (EIA, 2015). We do this directly, in the case of future biopower and co-firing levels, and indirectly through GDP, housing starts, and diesel prices for other forest products. Figure 7.3 shows the projected annual change for solid wood products measured in million cubic meters (m^3), pulpwood products such as paper and pellets measured in million metric tonnes (Mt), and biopower measured in gigawatt hours (GWh). Future demand for solid wood products such as lumber, plywood, and panels is shaped in large part by the AEO2015 assumption that housing starts will continue to recover from 2008 recession levels through 2020, at which point they will level off and future demand growth will be primary GDP-related. On the pulpwood side, projected paper and pellet growth will initially decline with continued substitution away from newsprint and graphics paper to digital media (Latta et al, 2016), but with that effect muted over time as paperboard and pellet demand grows. While near term growth rates for non-scenario specific bioenergy expansion appear high they are accrued on a low initial level leading in little gain in overall forest product market share.

Harvests on private forestland in the United States are determined as log purchasers minimize costs to meet aggregate national demand. Public harvests are assumed to be policy, rather than market driven and are constrained to occur at 15-year average levels within the state, not to exceed the maximum county-level over the same time period. As all forest resource data are maintained in units of biomass, live-tree carbon is assumed to be one half of the biomass weight. Model projections focus on the facility-level implications of a change in biopower demand.

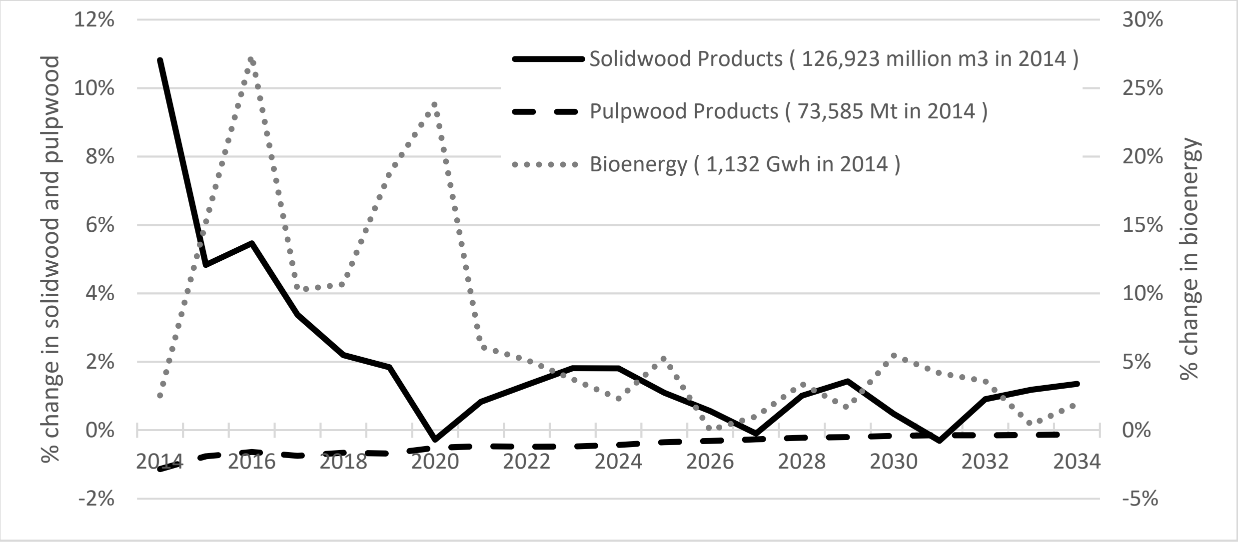
The effect of "leakage" on net carbon emissions is important in at least two ways. First, in-state facilities may procure biomass from neighboring states, from which net changes in emissions are not captured in the Washington calculation. Second, facilities in neighboring states could procure biomass from Washington, which would shift Washington supply sources and market prices. Therefore caution must be exercised when interpreting results where new facility impacts are limited to in-state forest emissions, which may under or overestimate net change. Finally, LURA is most appropriately used to project near-term dynamics, so estimates are only provided for the first 20 years (2015-2035) of alternative bioenergy scenarios.

Table 7.10. Total number of wood using facilities, production capacity, and foreign trade for wood products in Washington, 2014 (Source: Latta et al. 2018).

Forest Product		**Facilities**	**Capacity**	**Foreign trade**[*]	
				Exports	**Imports**
		---- # ----	*----- million* m^3 *-----*	*---- million dollars ----*	
Roundwood	softwood			897.5	45.2
	hardwood			11.8	4.7
Lumber	softwood	37	7,350	399.8	765.3
	hardwood	5	853	527.6	782.4
Plywood	softwood	7	404	200.9	183.8
	hardwood				
Cross laminated timber (CLT)					
Oriented strand board (OSB)				2.5	310.2
Medium-density fibreboard (MDF)				3.1	13.4
Other panel products					
			-- million tonnes (Mt) --		
Pulp	chemical	8	2,913	146.05	231.9
	mechanical	3	880	9.8	0.3
Newsprint		3	818	157.1	82.9
Print and writing paper		5	949	106.9	269.6
Paperboard		7	2,387	1,307.0	906.5
Tissue		2	276	2.4	16.0
Wood pellets		3	128	2.5	0.4
Chips	softwood			9.7	0.1
	hardwood			0.4	0.1
			------ MWh ------		
Forest biopower		7	32		
Forest co-firing		1	88		

*Port-level foreign trade data is 2010-2014 average from the United States International Trade Commission (USITC) Interactive Tariff and Trade Database (DataWeb), http://DataWeb.usitc.gov.

Figure 7.3. Projected change in national forest products industry production, 2014-2034.



7.5.2. Washington Model Scenarios

The carbon emissions analyzed here are a function of landscape live-tree carbon and power plant emissions from the combustion of biomass for energy generation. Landscape carbon is based on (1) forest growth and respiration (i.e., forest structure is a function of change in age class over time, decay, mortality), (2) removals (e.g., harvests, timber stand improvement and restoration projects), and (3) fire, disturbance (e.g. hurricanes), insects, and diseases infestations. The location of carbon emissions is further influenced by forest products market dynamics driving competition and subsequent feedstock purchasing behavior. This dynamic will affect the location and intensity of forest harvesting, which affects subsequent forest growth and respiration, and probability of wildfire occurrence. Total emissions are thus a function of the following variables, which form the basis for the scenarios modeled in Washington:

- Facility size and location – influences where the feedstock is procured, distance traveled, and price paid. The number and size of competing forest products industries within a procurement zone subsequently influences price and the distribution of feedstock by end product.
- Number of facilities – affects the distribution of feedstock demand, distance traveled, and associated emissions.
- Feedstock availability – function of land ownership, tree characteristics (species, size, age, and location), and projected growth and yield. Factors such as insect and fire mortality, or policy regulations will affect average annual harvest levels and availability by ownership.
- Feedstock type – the carbon emissions profile is influenced by the type of feedstock used for energy production. For instance, the ratio of clear-cutting to harvest thinnings, or the ratio of pulpwood to logging residuals influences carbon flux.
- Product demand – total wood products demand for the United States is assumed unchanged when adding bioenergy capacity. Total exports also remain static but the distribution of port activity and regional production changes with any new bioenergy.
- Conversion technology – changing the type of biopower facility and rated efficiency will affect the volume of feedstock needed to produce energy, which affects emissions. The type of offset fossil fuel (e.g., coal-fired power) and corresponding conversation efficiency is important.

In consultation with Washington forestry and regulatory agencies, six scenarios (Table 7.11) were selected to model net change in carbon emissions from using forest feedstocks for energy production.

Electricity generation is modeled for scenarios one through six varying facility size, number, and location (Figure 7.2). Each new facility is assumed to begin operations in 2019 collocated with existing or recently closed facilities. Feedstocks are constrained to biomass from logging residues in three of the scenarios; the allocation of sawlogs, pulpwood, and biomass is dictated by market dynamics in the other three scenarios. Logging residue utilization is capped at 60% of available limbs, tops or defect resulting from forest harvesting operations reflecting the proportion available in piles (Miller and Boston, 2017). The common practice and thus alternative fate in the region is burning residual piles resulting in instant emissions.

For each scenario we assume feedstock requirements, heat rate, and annual generation are scalable based on a 20 MW electricity-only facility with a heat rate of 15,000 Btu/kWh (23% efficiency), a capacity factor of 60% and a feedstock higher heating value of 12 MMBtu/ton. One 20 MW facility would require 131,400 dry tons of biomass, produce 105,120 MWh annually, and have smokestack emissions of 240,900 t CO_2 (2.29 t CO_2/MWh).

Table 7.11. Washington modeled scenarios of potential facility location, size, and feedstock.

Scenario	Forks	Raymond	Cle Elum	Everett	Key Assumptions
Washington 1	5 MW	5 MW	5 MW		Logging residues only
Washington 2	5 MW	5 MW	5 MW		
Washington 3	5 MW				
Washington 4		5 MW			Logging residues only
Washington 5			5 MW		Logging residues only
Washington 6				50 MW	

7.5.3. Washington Model Scenarios Results

We used LURA to model a baseline reference case and the six Washington scenarios over the 2014 to 2035 time period. Emissions are expressed as an average annual net change in landscape live-tree carbon from 2019 when the simulated facilities come online through 2035, and where applicable on an average annual MWh basis for electricity production. Net change is measured from the 2019 to 2035 baseline average values.

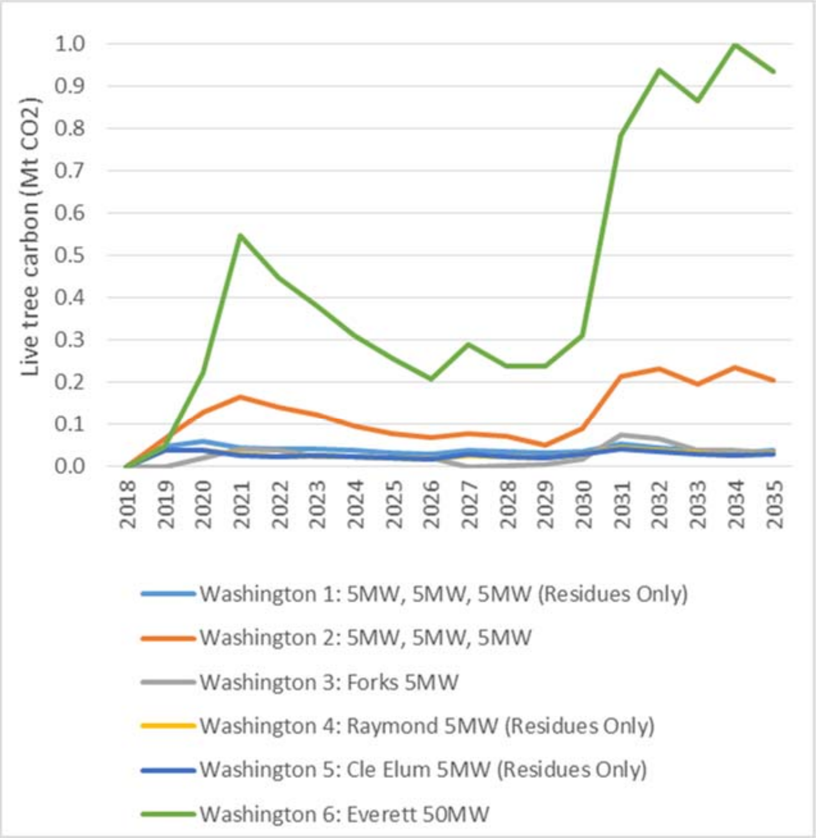
We do not assume that forest biomass is carbon neutral. Rather, forest carbon is accounted for in real-time. A net increase in GHG emissions occurs when forest carbon storage in a bioenergy scenario is lower than that of the baseline. Alternatively, a net decrease in GHG emissions occurs when there is more forest carbon stored in the bioenergy scenario than in the baseline. In both bioenergy and baseline scenarios, forest carbon totals are aggregated from live tree, dead tree, understory, down dead, and forest floor pools.

To fully understand the magnitude of biopower on net emissions, it is important to understand the overall trends in forest inventories in the baseline reference. The LURA model projects forest inventories to increase across the United States, but at a decreasing rate as a result of a slight decline in net growth. In Washington, the average forest carbon sequestration rate in the final 5 years of the baseline simulation (2031 to 2035) is 16% lower than that of the first five years (2015 to 2019), while at the national level the difference between sequestration over those same two periods is -46%. This reduction in sequestration is due in part to higher near term harvest increases associated with the revival of housing construction and in part to the aging of Northeastern and western federal forests. These trends are robust across scenarios, suggesting that net changes in carbon emissions are more a function of larger resource and market dynamics, and have less to do with the operation of bioenergy facilities in Washington, at least at the scales modeled.

Compared to the baseline, the residual-only scenarios (#1,4,5) yielded among the lowest average annual net emissions over the 17-year horizon (Table 7.12). Scenario #1 with three new 5 MW biomass electricity facilities dispersed throughout the state was about 19% of scenario #2 in-state emissions with the same facilities but where biomass feedstocks were not constrained to logging residuals. The difference between scenarios #3 and either #4 or #5 are greater, with and without logging residuals but only when looking at total in-state and out-of-state emissions; in-state emissions are nearly identical. By constraining feedstock supply to only logging residuals, scenarios #4 and #5 provide an additional revenue stream increasing in-state harvest that has a compensating reduction in out-of-state harvests. The reliance on roundwood in scenario #3 yields a similar increase in in-state harvest but as that harvest competes with traditional forest products uses it leads to a reduction in in-state production and a compensating increase in out-of-state production. The degree to which logging residues changes the emissions profile is based in large part on the degree to which the facility size is scaled appropriately to nearby wood products manufacturing and thus timber harvesting.

The influence of facility size is most apparent in scenario #6 where average annual live-tree emissions in Washington were 55,008 t CO_2 or 0.21 t CO_2/MWh. Emissions occurring outside Washington from shifts in production caused by the Everett 50 MW facility were fairly substantive given the relatively small change in biomass demand, which is possibly due to the importance of pulp and paper in the state's forest economy (Table 7.10). Cumulative carbon stock change[52] depicted in Figure 7.4 shows an initial period of little change prior to production coming online in 2019, followed by rapid increase in emissions rates from 2019 to 2021 as local harvest patterns quickly adjust to the new biomass demand. The remainder of the time horizon is punctuated by cycles of decreased and increased live-tree carbon averaging out at a level above the period just after facility production began. Dynamic forest product markets are causing ripple effects in competing industries, which changes the distribution of logging activity of the price industries are willing to pay for sawlogs, which drives the availability of biomass. The impact on carbon emissions is negligible for all but scenario #6.

Figure 7.4. Cumulative carbon stock change from baseline for Washington scenarios, 2018 – 2035.



To understand the impact of any scenario, annual emissions from biomass need to be compared to annual emissions from the reference condition using fossil

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[52] Change in cumulative carbon stock is calculated as the difference in the scenario carbon stock in a given year to the baseline carbon stocks in the same year.

fuels to produce the same amount of energy (26,280 MWh/yr to 262,800 MWh/yr). Net change in projected forest carbon emissions were compared to the 10-year average in-state coal and natural gas carbon emissions (Table 7.1) to illustrate possible offsets by modeled scenario. Actual offsets would require comparison to future fossil fuel emissions. Positive values indicate a net displacement of fossil fuel emissions, or decline in total emissions; negative values indicate a net increase in total emissions as a result of the scenario. Results in Table 7.12 illustrate that total carbon emissions would be less for each biopower scenario when compared to the 10-year average fossil fuel alternative. The largest decline in emissions are observed comparing to coal power and range from 0.86 t CO2/MWh (scenario #6) up to 1.04 t CO2/MWh (scenario #1).

Table 7.12. Average annual net change in landscape live tree carbon emissions, 2019-2035.

Scenario	Feedstock consumption (t/yr)	Power plant emissions (tonnes CO2/yr)	Energy generation (MWh/yr)	Total live tree emissions (tCO2/yr)	Minnesota live tree emissions (tCO2/yr)	Minnesota live tree energy intensity (tCO2/MWh)	Net fossil fuel energy intensity displacement (tCO2/MWh)*	
							Coal	NG
Washington 1	98,550	180,544	78,840	-824	2,239	0.03	1.04	0.42
Washington 2	98,550	180,544	78,840	17,036	12,047	0.15	0.92	0.30
Washington 3	32,850	60,181	26,280	7,654	1,916	0.07	1.00	0.38
Washington 4	32,850	60,181	26,280	-404	1,827	0.07	1.00	0.38
Washington 5	32,850	60,181	26,280	-1,204	1,749	0.07	1.00	0.38
Washington 6	328,500	601,812	262,800	64,135	55,008	0.21	0.86	0.24

*Net change in average annual emissions comparing bioenergy scenarios (years 2019-2035) to coal and natural gas (NG) (years 2006-2015). Positive values indicate a net decrease in total emissions; negative values indicate a net increase in total emissions. Observed average annual energy intensity of coal (1.07 tCO2/MWh) and natural gas (0.45 tCO2/MWh) are documented in Table 7.1.

7.6. Conclusion

The impact of new bioenergy production on carbon emissions in Washington is most influenced by whether or not feedstocks are constrained to logging residues, at least as the scales modeled. The residual-only scenarios yielded the lowest average annual net emissions over the 17-year horizon (Table 7.12). Net annual emissions are negligible or even negative for out-of-state impacts for all but scenario #6, suggesting that the scale of modeled production has little impact on statewide GHG profiles. Comparing results to the baseline condition from 2019 to 2035 also suggests that net emissions are more likely a function of changes in national resource conditions and market dynamics than with the operation of bioenergy facilities in Washington. As reported, changes are projected to have direct effects on landscape forest carbon, but the total GHG implications of changes in energy systems requires that net forest emissions be compared against a reference condition in which fossil fuels or other generation technologies are used. Projected forest emissions were compared to the 10-year in-state coal and natural gas emissions (2006-2015) to illustrate possible carbon offsets by modeled scenario. But comparison to future fossil fuel emissions was beyond the scope of this analysis and remains an important area for further research.

7.7. References

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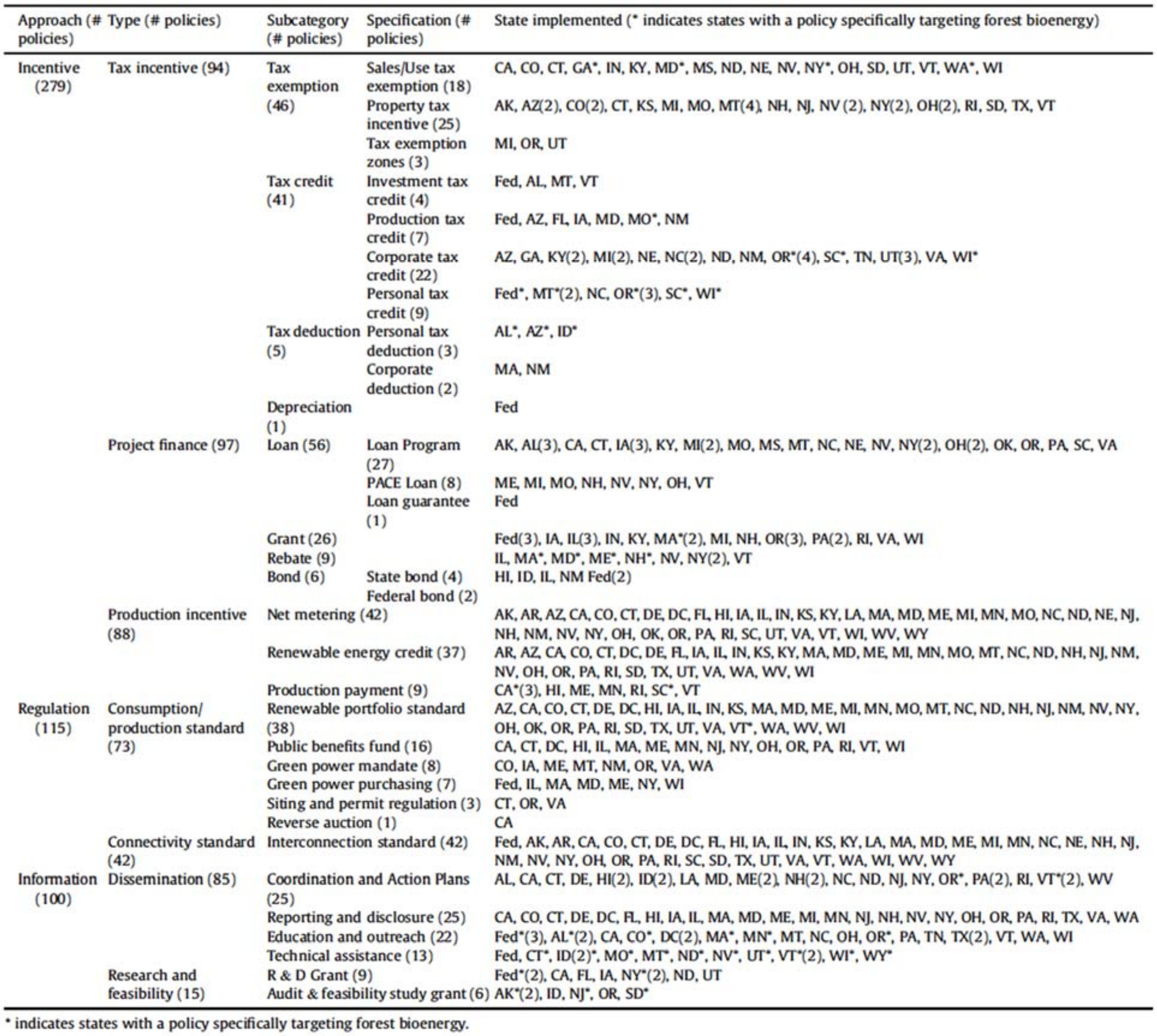
7.8. Appendix A:

Ebers et al. (2016) Classification of State's Policy Approaches for Forest Biomass Production.



Approach (# policies)	Type (# policies)	Subcategory (# policies)	Specification (# policies)	State implemented (* indicates states with a policy specifically targeting forest bioenergy)
Incentive (279)	Tax incentive (94)	Tax exemption (46)	Sales/Use tax exemption (18)	CA, CO, CT, GA*, IN, KY, MD*, MS, ND, NE, NV, NY*, OH, SD, UT, VT, WA*, WI
			Property tax incentive (25)	AK, AZ(2), CO(2), CT, KS, MI, MO, MT(4), NH, NJ, NV (2), NY(2), OH(2), RI, SD, TX, VT
			Tax exemption zones (3)	MI, OR, UT
		Tax credit (41)	Investment tax credit (4)	Fed, AL, MT, VT
			Production tax credit (7)	Fed, AZ, FL, IA, MD, MO*, NM
			Corporate tax credit (22)	AZ, GA, KY(2), MI(2), NE, NC(2), ND, NM, OR*(4), SC*, TN, UT(3), VA, WI*
			Personal tax credit (9)	Fed*, MT*(2), NC, OR*(3), SC*, WI*
		Tax deduction (5)	Personal tax deduction (3)	AL*, AZ*, ID*
			Corporate deduction (2)	MA, NM
		Depreciation (1)		Fed
	Project finance (97)	Loan (56)	Loan Program (27)	AK, AL(3), CA, CT, IA(3), KY, MI(2), MO, MS, MT, NC, NE, NV, NY(2), OH(2), OK, OR, PA, SC, VA
			PACE Loan (8)	ME, MI, MO, NH, NV, NY, OH, VT
			Loan guarantee (1)	Fed
		Grant (26)		Fed(3), IA, IL(3), IN, KY, MA*(2), MI, NH, OR(3), PA(2), RI, VA, WI
		Rebate (9)		IL, MA*, MD*, ME*, NH*, NV, NY(2), VT
		Bond (6)	State bond (4) Federal bond (2)	HI, ID, IL, NM Fed(2)
	Production incentive (88)	Net metering (42)		AK, AR, AZ, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, NC, ND, NE, NJ, NH, NM, NV, NY, OH, OK, OR, PA, RI, SC, UT, VA, VT, WI, WV, WY
		Renewable energy credit (37)		AR, AZ, CA, CO, CT, DC, DE, FL, IA, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, OH, OR, PA, RI, SD, TX, UT, VA, WA, WV, WI
		Production payment (9)		CA*(3), HI, ME, MN, RI, SC*, VT
Regulation (115)	Consumption/ production standard (73)	Renewable portfolio standard (38)		AZ, CA, CO, CT, DE, DC, HI, IA, IL, IN, KS, MA, MD, ME, MI, MN, MO, MT, NC, ND, NH, NJ, NM, NV, NY, OH, OK, OR, PA, RI, SD, TX, UT, VA, VT*, WA, WV, WI
		Public benefits fund (16)		CA, CT, DC, HI, IL, MA, ME, MN, NJ, NY, OH, OR, PA, RI, VT, WI
		Green power mandate (8)		CO, IA, ME, MT, NM, OR, VA, WA
		Green power purchasing (7)		Fed, IL, MA, MD, ME, NY, WI
		Siting and permit regulation (3)		CT, OR, VA
		Reverse auction (1)		CA
	Connectivity standard (42)	Interconnection standard (42)		Fed, AK, AR, CA, CO, CT, DE, DC, FL, HI, IA, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, NC, NE, NH, NJ, NM, NV, NY, OH, OR, PA, RI, SC, SD, TX, UT, VA, VT, WA, WI, WV, WY
Information (100)	Dissemination (85)	Coordination and Action Plans (25)		AL, CA, CT, DE, HI(2), ID(2), LA, MD, ME(2), NH(2), NC, ND, NJ, NY, OR*, PA(2), RI, VT*(2), WV
		Reporting and disclosure (25)		CA, CO, CT, DE, DC, FL, HI, IA, IL, MA, MD, ME, MI, MN, NJ, NH, NV, NY, OH, OR, PA, RI, TX, VA, WA
		Education and outreach (22)		Fed*(3), AL*(2), CA, CO*, DC(2), MA*, MN*, MT, NC, OH, OR*, PA, TN, TX(2), VT, WA, WI
		Technical assistance (13)		Fed, CT*, ID(2)*, MO*, MT*, ND*, NV*, UT*, VT*(2), WI*, WY*
	Research and feasibility (15)	R & D Grant (9)		Fed*(2), CA, FL, IA, NY*(2), ND, UT
		Audit & feasibility study grant (6)		AK*(2), ID, NJ*, OR, SD*

* indicates states with a policy specifically targeting forest bioenergy.