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March 6, 2019

Ms. Karen G. Sabasteanski
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RE: Re-proposed Regulations to Reduce and Cap Carbon Dioxide from Fossil Fuel-Fired Electric Power Generating Facilities (Revision C17)

Dear Ms. Sabasteanski:

On behalf of Appalachian Voices and Wetlands Watch, the Southern Environmental Law Center ("SELC") is pleased to submit the following comments on the Virginia Department of Environmental Quality ("DEQ") re-proposed regulations to "Reduce and Cap Carbon Dioxide ("CO_2") from Fossil Fuel Fired Electric Power Generating Facilities."

We commend DEQ for continuing to demonstrate strong leadership in Virginia in the absence of leadership at the federal level on this issue. Climate change threatens the Commonwealth of Virginia in numerous ways. As sea levels continue to rise, coastal flooding—already a fact of life in Norfolk, Hampton Roads, and other areas—will worsen. More extreme weather will mean stronger storm surges, more catastrophic rainfall events, and increased heat waves. In the Southeast, increased temperatures will result in more heat-related illnesses and death, and will also worsen air quality, leading to respiratory and other health problems. Increases in vector-borne diseases are expected as conditions for ticks and mosquitos become more favorable. Increased water stress and drought will not only adversely affect public health, but are also expected to hurt rural economies in the Southeast.[1] As climate change will affect the health and well-being of Virginians throughout the Commonwealth, it remains vital that Virginia continue to pursue action and address carbon emissions head on at the state and local level.

[1] Attachment 1, U.S. Global Change Research Program, Fourth National Climate Assessment, Ch. 19: Southeast 743-808 (2018), https://nca2018.globalchange.gov/downloads/NCA4_Ch19_Southeast_Full.pdf (full report available at: https://nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf.).

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SELC reiterates its comments on the original proposed carbon regulations[2] and offers the following additional comments to help guide and support DEQ as it continues to develop final regulations that will best meet the goal of reducing statewide CO_2 emissions.

1. **The re-proposed budget is based on more accurate modeling and assumptions and is necessary to meet the goals of the proposed regulation.**

As SELC stated in its comments on the original proposal, we support a 2020 emissions baseline that best achieves DEQ's goal of reducing statewide carbon pollution. SELC agrees the re-proposed 2020 base budget of 28 million tons does just that. The updated and revised modeling assumptions show that Virginia's CO_2 Budget Sources' business-as-usual emissions will be 28 million tons of CO_2 in 2020. This baseline appears far more accurate than the originally proposed base budgets of 33 or 34 million tons, which were significantly higher than recent actual emissions. The new modeling relied on more current data and more realistic assumptions, incorporating increases in renewable energy and energy efficiency coming on line in Virginia as a result of the 2018 Grid Transformation & Security Act,[3] new demand projections, updated natural gas prices, new RGGI states, and significant new clean energy deployments in the RGGI states.[4] As a result, the updated model produced a more accurate business-as-usual scenario for 2020 than originally proposed, which relied on outdated assumptions.

a. **Increases in energy efficiency and renewable energy investments under the Grid Transformation & Security Act will reduce electricity demand and carbon emissions in Virginia.**

The 2018 GTSA requires Dominion Energy and Appalachian Power to propose $1.01 billion in energy efficiency investments by 2028.[5] Energy efficiency programs can significantly reduce peak demand. As we noted in previous comments, a study of Virginia's possible energy efficiency future by Applied Economics Clinic found that under a "medium efficiency" scenario, total annual electricity sales in Dominion's territory could actually decrease.[6] Indeed, the study shows annual efficiency savings between 1,813 GWh and 2,840 GWh by 2028 under "low efficiency" or "medium efficiency" scenarios, respectively.[7] Given these significant potential demand savings from energy efficiency initiatives, it is clear that the re-proposed base budget of 28 million tons, which factored in future energy efficiency investments in Virginia, is more realistic than the original budgets. DEQ's decision to include these investments in the revised

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[2] Southern Envtl. Law Ctr., Comments on Proposed Regs. to Reduce and Cap Carbon Dioxide from Fossil Fuel Fired Elec. Power Generating Facilities (Revision C17) (Apr. 8, 2018), https://www.deq.virginia.gov/Portals/0/DEQ/Air/GHG/selc.pdf, ("SELC Comments").

[3] 2018 Va. Acts ch. 296 ("GTSA").

[4] Dep't of Envtl. Quality, *Carbon Dioxide Trading Program (Rev. C17) Re-Proposed Regulation*, Slide 21-22 (Oct. 29, 2018), https://www.deq.virginia.gov/Portals/0/DEQ/Air/GHG/C17-reproposal.pptx.

[5] GTSA (Enactment Clause 15).

[6] Attachment 2, Elizabeth A. Stanton, *et al*., *Missed Opportunities for Efficiency in Virginia* 4 (Feb. 1, 2018), https://advocacy.consumerreports.org/wp-content/uploads/2018/02/Missed-Opportunities-for-EE-in-VA-Report-Final.pdf.

[7] *Id.*

modeling is also consistent with a recent ruling from the Virginia State Corporation Commission (the "Commission"). In December 2018, the Commission rejected Dominion Energy's 2018 Integrated Resource Plan ("IRP") in part due to the failure to include $870 million in proposed energy efficiency investments in the IRP load forecasting. The Commission insisted, and Dominion agreed, that a primary purpose of energy efficiency measures is to reduce load.[8] As such, the Commission required Dominion to assess the impact of the GTSA energy efficiency investments on load forecasts in its revised Integrated Resource Plan.[9]

Through the GTSA, the General Assembly also announced its intention to develop 5,000 MW of wind and solar projects in the Commonwealth by 2028.[10] As a result, Virginia's in-state generation fleet will necessarily become less carbon intensive, helping to achieve the carbon reductions proposed. The originally-proposed base budgets did not include this increase in renewables as an assumption and therefore overstated future carbon emissions in the state. The new base budget of 28 million tons, which assumes 5,000 MW of renewables by 2028, is a more accurate reflection of future CO_2 emission levels in Virginia.

b. Updated demand projections also resulted in a more accurate base budget.

DEQ's consideration of new demand projections also produced a more realistic base budget. As with the consideration of energy efficiency investments and increases in renewable energy, an updated demand projection is consistent with the Commission's findings in its December 2018 Final Order on Dominion's IRP. DEQ relied on Dominion's 2017 IRP load forecast in its original modeling; however, the Commission concluded in December 2018 that Dominion's load forecast has been overstated for years, despite generally flat actual demand.[11] Indeed, Dominion's load forecast was almost double PJM's projections.[12] In light of this finding, and in light of decreased demand in RGGI states, SELC supports DEQ's decision to update demand projection and agrees this resulted in a more accurate beginning base budget and future reduction goals.

In sum, the proposed base budget of 28 million tons—based on better modeling and more realistic demand projections—is well supported by the record.

2. The final regulation should cover all electric power facilities that emit carbon dioxide, regardless of fuel type.

As proposed, the regulation plainly and unambiguously applies to fossil fuel-fired units that co-fire with biomass.

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[8] Attachment 3, *In re: Va. Elec. and Power Co.'s Integrated Res. Plan filing pursuant to Va. Code § 56.597 et seq.*, Case. No. PUR-2018-00065, Order 8 (Dec. 7, 2018), http://www.scc.virginia.gov/docketsearch/DOCS/4d5g01!.PDF ("IRP Order").

[9] *Id.*

[10] GTSA (amending Va. Code § 56-585.1(A)(6)).

[11] Attachment 3, IRP Order at 7.

[12] *Id.* at 6.

In particular, the regulation defines "fossil fuel-fired" as "combustion of fossil fuel, alone *or in combination with any other fuel*, where the fossil fuel combusted comprises, or is projected to comprise, more than 5% of the annual heat input on the Btu basis during any year."[13] The regulation then states that "[a]ny fossil fuel-fired unit that serves an electricity generator with a nameplate capacity equal to or greater than 25MWe shall be a CO_2 budget unit, and any source that includes one or more such units shall be a CO_2 budget source, subject to the requirements of this part."[14] Together, these two provisions make clear that the regulations cover ***all*** units that co-fire fossil fuel with biomass, so long as the fossil fuel comprises more than 5 percent of the annual heat input. The only co-fired units that would not be subject to the requirements of the regulation are units where biomass accounts for 95 percent or more of the annual heat input, with fossil fuel accounting for 5 percent or less.

Importantly, an owner of a co-fired unit subject to the regulation must obtain sufficient CO_2 allowances to offset ***all*** of the unit's CO_2 emissions. The proposed regulation makes clear that an owner or operator must hold allowances for "***total*** CO_2 emissions . . . from all CO_2 budget units at the source."[15] Since co-fired units that burn less than 95 percent biomass are by definition a fossil fuel-fired unit and a CO_2 budget unit, an owner or operator must have CO_2 allowances to offset all emissions from such a unit.

We support this approach. Inclusion of all CO_2 emissions, regardless of fuel type, best achieves the goals of these carbon reduction regulations. Additionally, attempting to distinguish between CO_2 emissions from various fuel types would be difficult to implement and enforce, causing a significant administrative burden on both covered sources and the Department. Thus, requiring that CO_2 Budget Sources hold allowances for all CO_2 emissions makes good sense from a policy perspective and furthers the goals of the regulations.[16]

While we support the proposed regulation's coverage of co-fired biomass units, we reiterate our request that DEQ amend the regulation so that ***all*** biomass units with nameplate capacities equal to or greater than 25 MWe are subject to the requirements, not merely co-fired units.[17] The science is clear: burning wood for electricity is not inherently carbon neutral and results in an immediate net increase of atmospheric CO_2 for decades to centuries.[18] While including co-fired

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[13] CO_2 Budget Trading Program, 35 Va. Reg. Regs. 1409, 1413 (proposed Feb. 4, 2019) (to be codified at 9 Va. Admin. Code §5-140-6010 *et seq*.). (emphasis supplied).

[14] CO_2 Budget Trading Program, 35 Va. Reg. Regs. at 1416.

[15] *Id.* (emphasis supplied).

[16] SELC requests that DEQ amend the summary of change preceding the re-proposed regulations in the Virginia Register in order to make it consistent with the rule. As currently written, the summary states that "substantive changes in the reproposed action include . . . exemption of fossil fuel units that co-fire with biomass from CO_2 accounting." CO_2 Budget Trading Program, 35 Va. Reg. Regs. at 1409. This statement directly conflicts with the text of the actual regulation and should be removed. It appears to be a remnant from a prior version of the regulation.

[17] SELC Comments at 3.

[18] *See, e.g.*, Attachment 4, Biomass Energy Resource Center, Forest Guild, Spatial Informatics Group, *Biomass Supply and Carbon Accounting for Southeastern Forests* (Feb. 2012), https://www.biomasscenter.org/images/stories/SE_Carbon_Study_FINAL_2-6-12.pdf; Attachment 5, Duncan Brack, Chatham House, *Woody Biomass for Power and Heat: Impacts on the Global Climate* (2017), https://www.chathamhouse.org/publication/woody-

biomass units in the regulation is a good start, there is no principled reason to exempt other biomass units. Biomass units generate CO_2 emissions just like fossil fuel-fired and co-fired units, and should be covered in order to better reduce the carbon emissions from electric generation in Virginia.

3. **The 5 percent energy efficiency set aside is an important measure for furthering the purposes of the regulations.**

SELC reiterates its support for the set aside to assist the Virginia Department of Mines, Minerals, and Energy (DMME) in efforts to abate and control air pollution through energy efficiency programs. This set aside will play an important role in both furthering the purposes of the regulations and offsetting the costs. In addition to reductions in demand, energy efficiency programs can result in lower costs for customers. In the study by Applied Economics Clinic discussed above, "low efficiency" or "medium efficiency" scenarios in Virginia could decrease customers' annual electric bills by $41 to $92 in 2028, with cumulative customer bill savings totaling $800 million to $1.7 billion between 2018 and 2028.[19] The "medium efficiency" scenario can deliver up to 5.74 percent average reduction in bills in 2028.[20] As a result, the set aside will not only play a key role in continuing to lower demand and, in turn, carbon emissions in Virginia, but it will also be an important part of reducing the costs of the program on customers and CO_2 budget units.

We also reiterate our previous suggestion encouraging DEQ to consider whether a 10 percent set aside would produce more benefits than it would increase costs for covered entities.[21]

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biomass-power-and-heat-impacts-global-climate; Attachment 6, European Academies Science Advisory Council, *Multi-Functionality and Sustainability in the European Union's Forest* (2017), https://www.easac.eu/fileadmin/PDF_s/reports_statements/Forests/EASAC_Forests_web_complete.pdf; Attachment 7, John D. Sterman, et al., *Does Replacing Coal with Wood Lower CO2 Emissions? Dynamic Lifecycle Analysis of Wood Bioenergy* (2018), http://iopscience.iop.org/article/10.1088/1748-9326/aaa512/meta; Duncan Brack, Chatham House, *Woody Biomass for Power and Heat: Impacts on the Global Climate* (2017), https://www.chathamhouse.org/publication/woody-biomass-power-and-heat-impacts-global-climate; Attachment 8, Letter from Scientists to the European Parliament Regarding Forest Biomass (updated Jan. 14, 2018); Attachment 9, Mary S. Booth, *Not Carbon Neutral: Assessing the Net Emissions Impact of Residues Burned for Bioenergy* (Feb. 2018), http://iopscience.iop.org/article/10.1088/1748-9326/aaac88/meta.

[19] Attachment 2, Stanton *et. al*, at i.

[20] *Id.* at 14

[21] SELC Comments at 5.

March 6, 2019

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Attachments	
Attachment 1	U.S. Global Change Research Program, Fourth National Climate Assessment, Ch. 19: Southeast (2018), https://nca2018.globalchange.gov/downloads/NCA4_Ch19_Southeast_Full.pdf.
Attachment 2	Elizabeth A. Stanton, *et al*., *Missed Opportunities for Efficiency in Virginia* (Feb. 1, 2018), https://advocacy.consumerreports.org/wp-content/uploads/2018/02/Missed-Opportunities-for-EE-in-VA-Report-Final.pdf.
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Attachment 7	John D. Sterman, *et al*., *Does Replacing Coal with Wood Lower CO2 Emissions? Dynamic Lifecycle Analysis of Wood Bioenergy* (2018), http://iopscience.iop.org/article/10.1088/1748-9326/aaa512/meta.
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Attachment 1

19 Southeast

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On the Web: https://nca2018.globalchange.gov/chapter/southeast

19 Southeast

Red mangrove in Titusville, Florida

Key Message 1

Urban Infrastructure and Health Risks

Many southeastern cities are particularly vulnerable to climate change compared to cities in other regions, with expected impacts to infrastructure and human health. The vibrancy and viability of these metropolitan areas, including the people and critical regional resources located in them, are increasingly at risk due to heat, flooding, and vector-borne disease brought about by a changing climate. Many of these urban areas are rapidly growing and offer opportunities to adopt effective adaptation efforts to prevent future negative impacts of climate change.

Key Message 2

Increasing Flood Risks in Coastal and Low-Lying Regions

The Southeast's coastal plain and inland low-lying regions support a rapidly growing population, a tourism economy, critical industries, and important cultural resources that are highly vulnerable to climate change impacts. The combined effects of changing extreme rainfall events and sea level rise are already increasing flood frequencies, which impacts property values and infrastructure viability, particularly in coastal cities. Without significant adaptation measures, these regions are projected to experience daily high tide flooding by the end of the century.

Key Message 3

Natural Ecosystems Will Be Transformed

The Southeast's diverse natural systems, which provide many benefits to society, will be transformed by climate change. Changing winter temperature extremes, wildfire patterns, sea levels, hurricanes, floods, droughts, and warming ocean temperatures are expected to redistribute species and greatly modify ecosystems. As a result, the ecological resources that people depend on for livelihood, protection, and well-being are increasingly at risk, and future generations can expect to experience and interact with natural systems that are much different than those that we see today.

Key Message 4

Economic and Health Risks for Rural Communities

Rural communities are integral to the Southeast's cultural heritage and to the strong agricultural and forest products industries across the region. More frequent extreme heat episodes and changing seasonal climates are projected to increase exposure-linked health impacts and economic vulnerabilities in the agricultural, timber, and manufacturing sectors. By the end of the century, over one-half billion labor hours could be lost from extreme heat-related impacts. Such changes would negatively impact the region's labor-intensive agricultural industry and compound existing social stresses in rural areas related to limited local community capabilities and associated with rural demography, occupations, earnings, literacy, and poverty incidence. Reduction of existing stresses can increase resilience.

Executive Summary

The Southeast includes vast expanses of coastal and inland low-lying areas, the southern portion of the Appalachian Mountains, numerous high-growth metropolitan areas, and large rural expanses. These beaches and bayous, fields and forests, and cities and small towns are all at risk from a changing climate. While some climate change impacts, such as sea level rise and extreme downpours, are being acutely felt now, others, like increasing exposure to dangerous high temperatures, humidity, and new local diseases, are expected to become more significant in the coming decades. While all regional residents and communities are potentially at risk for some impacts, some communities or populations are at greater risk due to their locations, services available to them, and economic situations.

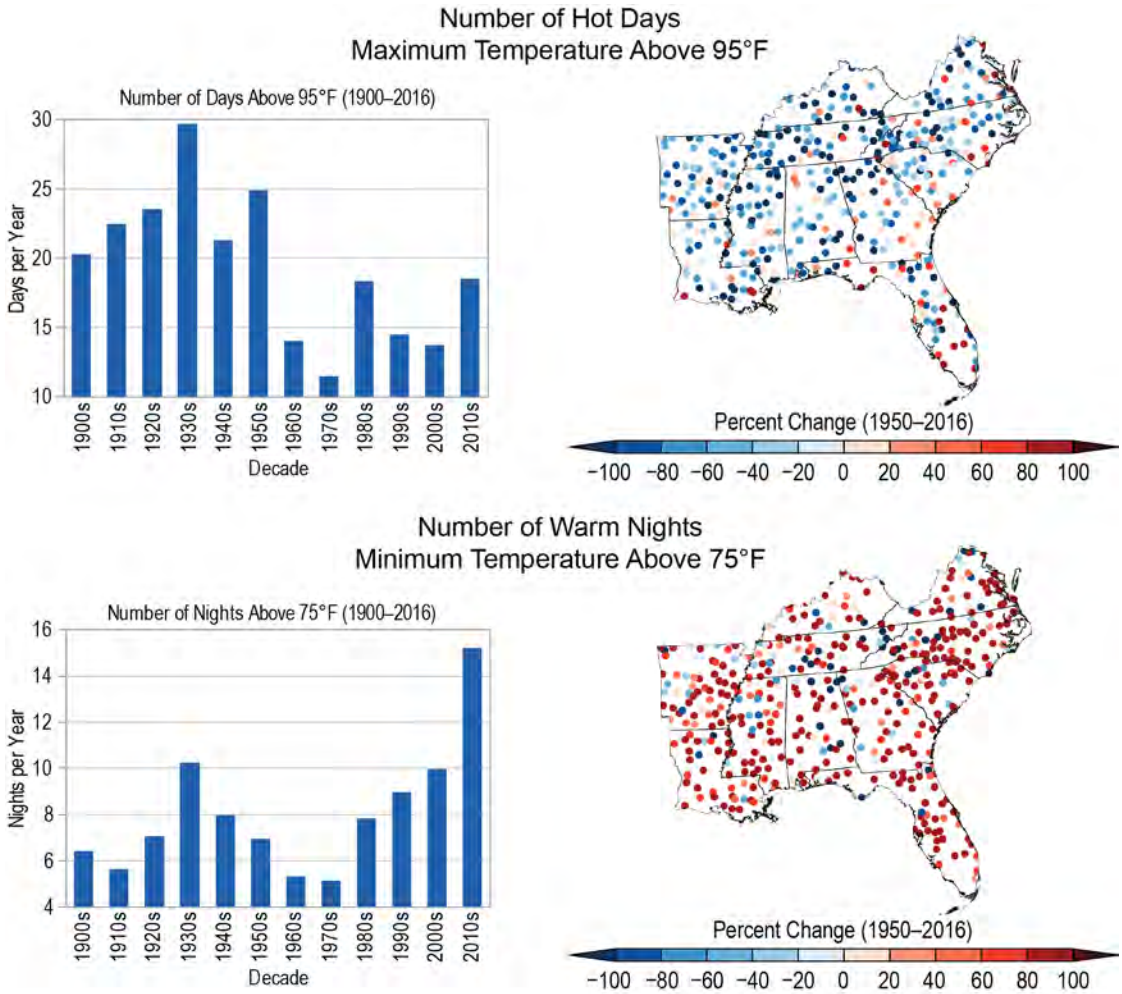
Observed warming since the mid-20th century has been uneven in the Southeast region, with average daily minimum temperatures increasing three times faster than average daily maximum temperatures. The number of extreme rainfall events is increasing. Climate model simulations of future conditions project increases in both temperature and extreme precipitation.

Trends towards a more urbanized and denser Southeast are expected to continue, creating new climate vulnerabilities. Cities across the Southeast are experiencing more and longer summer heat waves. Vector-borne diseases pose a greater risk in cities than in rural areas because of higher population densities and other human factors, and the major urban centers in the Southeast are already impacted by poor air quality during warmer months. Increasing precipitation and extreme weather events will likely impact roads, freight rail, and passenger rail, which will likely have cascading effects across the region. Infrastructure related to drinking water and wastewater treatment also has the potential to be compromised by climate-related events. Increases in extreme rainfall events and high tide coastal floods due to future climate change will impact the quality of life of permanent residents as well as tourists visiting the low-lying and coastal regions of the Southeast. Sea level rise is contributing to increased coastal flooding in the Southeast, and high tide flooding already poses daily risks to businesses, neighborhoods, infrastructure, transportation, and ecosystems in the region.[1,2] There have been numerous instances of intense rainfall events that have had devastating impacts on inland communities in recent years.

The ecological resources that people depend on for livelihoods, protection, and well-being are increasingly at risk from the impacts of climate change. Sea level rise will result in the rapid conversion of coastal, terrestrial, and freshwater ecosystems to tidal saline habitats. Reductions in the frequency and intensity of cold winter temperature extremes are already allowing tropical and subtropical species to move northward and replace more temperate species. Warmer winter temperatures are also expected to facilitate the northward movement of problematic invasive species, which could transform natural systems north of their current distribution. In the future, rising temperatures and increases in the duration and intensity of drought are expected to increase wildfire occurrence and also reduce the effectiveness of prescribed fire practices.[3,4,5,6]

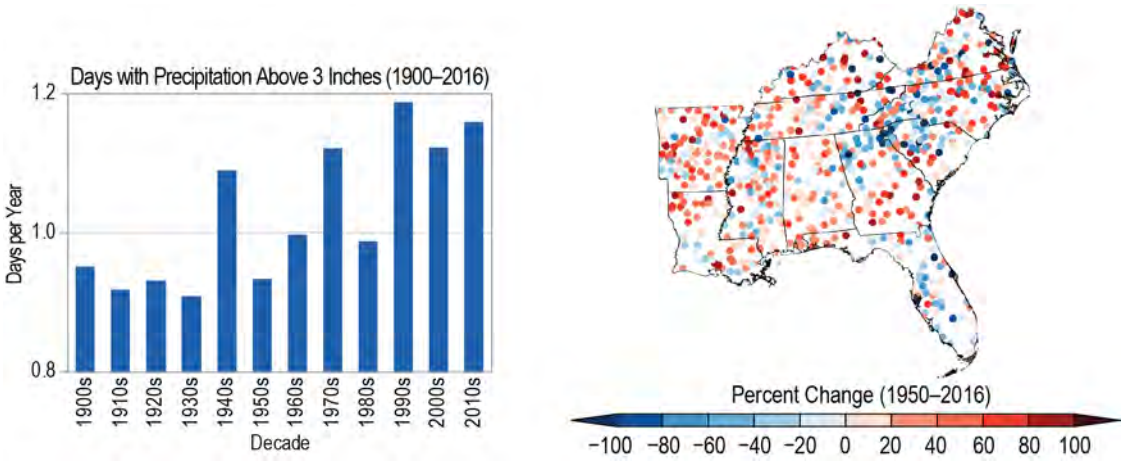
Many in rural communities are maintaining connections to traditional livelihoods and relying on natural resources that are inherently vulnerable to climate changes. Climate trends and possible climate futures show patterns that are already impacting—and are projected to further impact—rural sectors, from agriculture and forestry to human health and labor productivity. Future temperature increases are projected to pose challenges to human health. Increases in temperatures, water stress, freeze-free days, drought, and wildfire risks, together with changing conditions for invasive species and the movement of diseases, create a number of potential risks for existing agricultural systems.[7] Rural communities tend to be more vulnerable to these changes due to factors such as demography, occupations, earnings, literacy, and poverty incidence.[8,9,10] In fact, a recent economic study using a higher scenario (RCP8.5)[11] suggests that the southern and midwestern populations are likely to suffer the largest losses from future climate changes in the United States. Climate change tends to compound existing vulnerabilities and exacerbate existing inequities. Already poor regions, including those found in the Southeast, are expected to continue incurring greater losses than elsewhere in the United States.

Historical Changes in Hot Days and Warm Nights



Sixty-one percent of major Southeast cities are exhibiting some aspects of worsening heat waves, which is a higher percentage than any other region of the country.[12] Hot days and warm nights together impact human comfort and health and result in the need for increased cooling efforts. Agriculture is also impacted by a lack of nighttime cooling. Variability and change in (top) the annual number of hot days and (bottom) warm nights are shown. The bar charts show averages over the region by decade for 1900–2016, while the maps show the trends for 1950–2016 for individual weather stations. Average summer temperatures during the most recent 10 years have been the warmest on record, with very large increases in nighttime temperatures and more modest increases in daytime temperatures, as indicated by contrasting changes in hot days and warm nights. (top left) The annual number of hot days (maximum temperature above 95°F) has been lower since 1960 than the average during the first half of the 20th century; (top right) trends in hot days since 1950 are generally downward except along the south Atlantic coast and in Florida due to high numbers during the 1950s but have been slightly upward since 1960, following a gradual increase in average daytime maximum temperatures during that time. (bottom left) Conversely, the number of warm nights (minimum temperature above 75°F) has doubled on average compared to the first half of the 20th century and (bottom right) locally has increased at most stations. *From Figure 19.1 (Sources: NOAA NCEI and CICS-NC)*.

Historical Change in Heavy Precipitation



The figure shows variability and change in (left) the annual number of days with precipitation greater than 3 inches (1900–2016) averaged over the Southeast by decade and (right) individual station trends (1950–2016). The number of days with heavy precipitation has increased at most stations, particularly since the 1980s. *From Figure 19.3 (Sources: NOAA NCEI and CICS-NC)*

Background

Throughout the southeastern United States, the impacts of sea level rise, increasing temperatures, extreme heat events, heavy precipitation, and decreased water availability continue to have numerous consequences for human health, the built environment, and the natural world. This assessment builds on the above concerns described in the Third National Climate Assessment (NCA3) and includes impacts to urban and rural landscapes as well as natural systems. The impacts from these changes are becoming visible as 1) flooding increases stress on infrastructure, ecosystems, and populations; 2) warming temperatures affect human health and bring about temporal and geographic shifts in the natural environment and landscapes; and 3) wildfires and growing wildfire risk create challenges for natural resource managers and impacted communities.

The Southeast includes vast expanses of coastal and inland low-lying areas, the southern (and highest) portion of the Appalachian Mountains, numerous high-growth metropolitan areas, and large rural expanses. Embedded in these land- and seascapes is a rich cultural history developed over generations by the many communities that call this region home. However, these beaches and bayous, fields and forests, and cities and small towns are all at risk from a changing climate. These risks vary in type and magnitude from place to place, and while some climate change impacts, such as sea level rise and extreme downpours, are being acutely felt now, others, like increasing exposure to dangerously high temperatures—often accompanied by high humidity—and new local diseases, are expected to become more significant in the coming decades. While all regional residents and communities are potentially at risk for some impacts, some communities or populations are at greater risk due to their locations, services available, and economic situations. In fact, a recent economic study using a higher scenario (RCP8.5)[11] suggests that the southern and midwestern populations are likely to suffer the largest losses from projected climate changes in the United States. According to the article, "[b]ecause losses are largest in regions that are already poorer on average, climate change tends to increase preexisting inequality in the United States."[11] Understanding the demographic and socioeconomic composition of racial and ethnic groups in the region is important, because these characteristics are associated with health risk factors, disease prevalence, and access to care, which in turn may influence the degree of impact from climate-related threats.

Historical Climate and Possible Future Climates

The Southeast region experienced high annual average temperatures in the 1920s and 1930s, followed by cooler temperatures until the 1970s. Since then, annual average temperatures have warmed to levels above the 1930s; the decade of the 2010s through 2017 has been warmer than any previous decade (App 5: FAQs, Figure A5.14), both for average daily maximum and average daily minimum temperature. Seasonal warming has varied. The decade of the 2010s through 2017 is the warmest in all seasons for average daily minimum temperature and in winter and spring for average daily maximum temperature. However, for average daily maximum temperature, the summers of the 1930s and 1950s and the falls of the 1930s were warmer on average. The southeastern United States is one of the few regions in the world that has experienced little overall warming of daily maximum temperatures since 1900. The reasons for this have been the subject of much research, and hypothesized causes include both human and natural influences.[13,14,15,16,17] However, since the early 1960s, the Southeast has been warming at a similar rate as the rest of the United States (Ch.

2: Climate, Figure 2.4). During the 2010s, the number of nights with minimum temperatures greater than 75°F was nearly double the long-term average for 1901–1960 (Figure 19.1), while the length of the freeze-free season was nearly 1.5 weeks greater than any other period in the historical record (Figure 19.2). These increases were widespread across the region and can have important effects on both humans and the natural environment.[18] By contrast, the number of days above 95°F has been lower since 1960 compared to the pre-1960 period, with the highest numbers occurring in the 1930s and 1950s, both periods of severe drought (Figure 19.1). The differing trends in hot days and warm nights reflect the seasonal differences in average daily maximum and average daily minimum temperature trends.

Historical Changes in Hot Days and Warm Nights

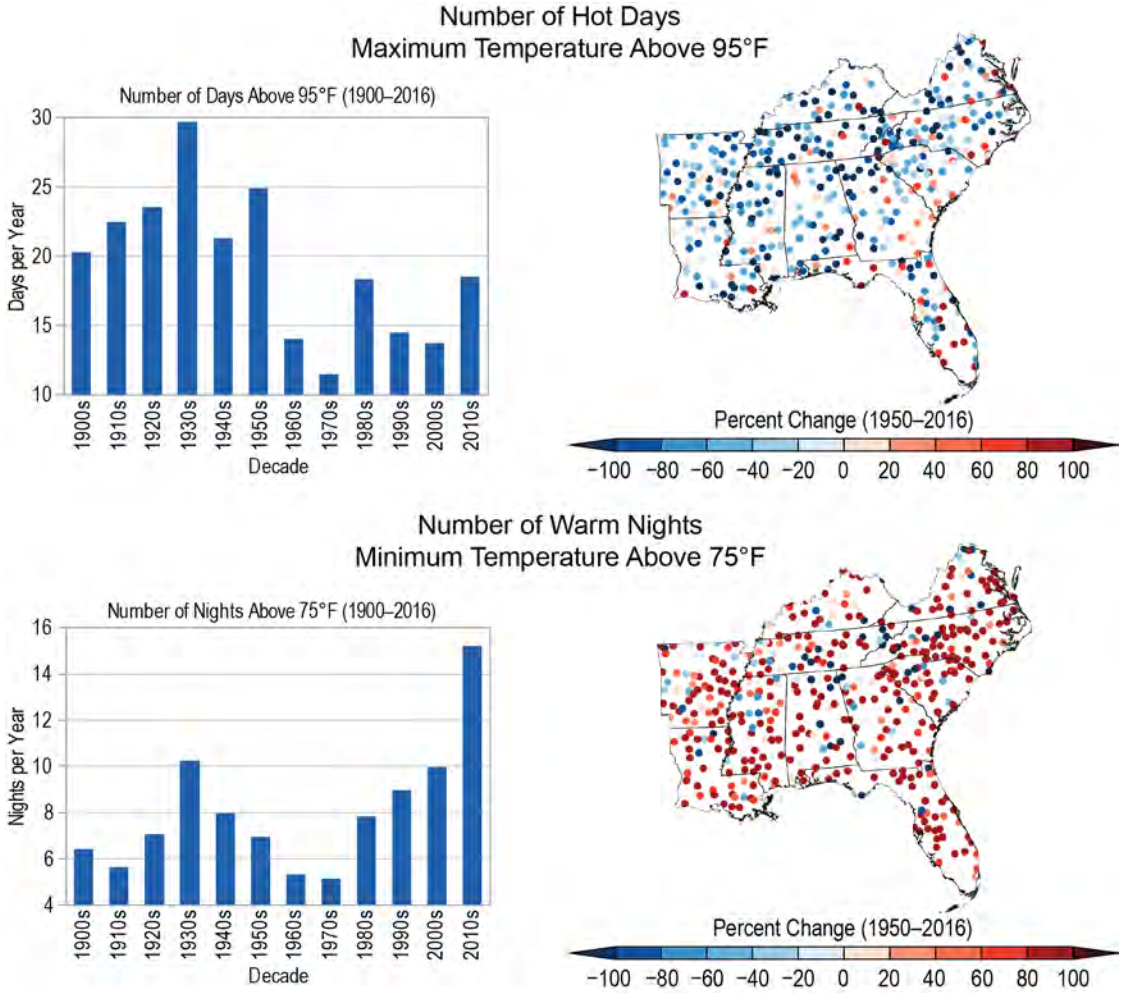


Figure 19.1: Sixty-one percent of major Southeast cities are exhibiting some aspects of worsening heat waves, which is a higher percentage than any other region of the country.[12] Hot days and warm nights together impact human comfort and health and result in the need for increased cooling efforts. Agriculture is also impacted by a lack of nighttime cooling. Variability and change in (top) the annual number of hot days and (bottom) warm nights are shown. The bar charts show averages over the region by decade for 1900–2016, while the maps show the trends for 1950–2016 for individual weather stations. Average summer temperatures during the most recent 10 years have been the warmest on record, with very large increases in nighttime temperatures and more modest increases in daytime temperatures, as indicated by contrasting changes in hot days and warm nights. (top left) The annual number of hot days (maximum temperature above 95°F) has been lower since 1960 than the average during the first half of the 20th century; (top right) trends in hot days since 1950 are generally downward except along the south Atlantic coast and in Florida due to high numbers during the 1950s but have been slightly upward since 1960, following a gradual increase in average daytime maximum temperatures during that time. (bottom left) Conversely, the number of warm nights (minimum temperature above 75°F) has doubled on average compared to the first half of the 20th century and (bottom right) locally has increased at most stations. Sources: NOAA NCEI and CICS-NC.

Historical Change in Freeze-Free Season Length

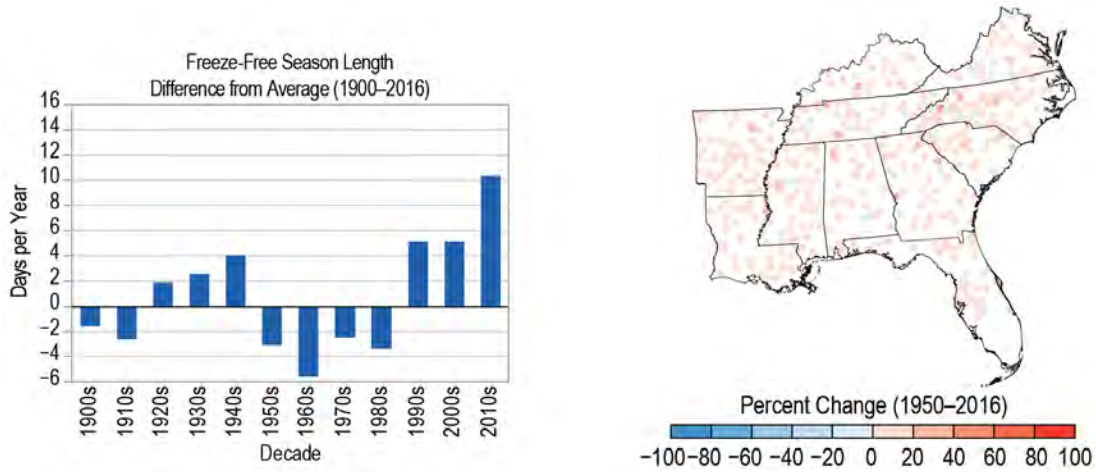


Figure 19.2: The figure shows the variability and change in the length of the freeze-free season. (left) The bar chart shows differences in the length of the freeze-free season by decade (1900–2016) as compared to the long-term average for the Southeast. (right) The map shows trends over 1950–2016 for individual weather stations. The length of the freeze-free season has increased at most stations, particularly since the 1980s. Sources: NOAA NCEI and CICS-NC.

Historical Change in Heavy Precipitation

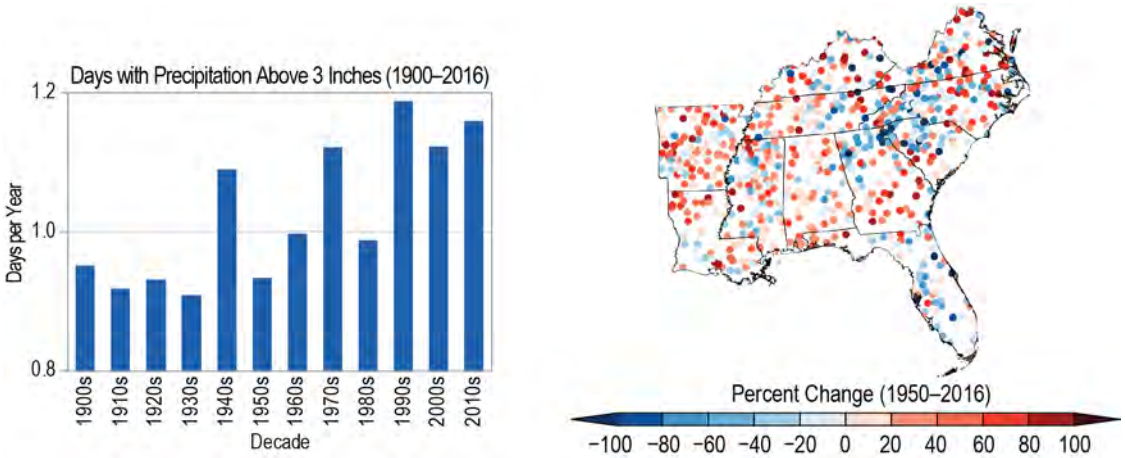


Figure 19.3: The figure shows variability and change in (left) the annual number of days with precipitation greater than 3 inches (1900–2016) averaged over the Southeast by decade and (right) individual station trends (1950–2016). The numbers of days with heavy precipitation has increased at most stations, particularly since the 1980s. Sources: NOAA NCEI and CICS-NC.

The number of extreme rainfall events is increasing. For example, the number of days with 3 or more inches of precipitation has been historically high over the past 25 years, with the 1990s, 2000s, and 2010s ranking as the decades with the 1st, 3rd, and 2nd highest number of events, respectively (Figure 19.3). More than 70% of precipitation recording locations show upward trends since 1950, although there are downward trends at many stations along and southeast of the Appalachian Mountains and in Florida (Figure 19.3).

Climate model simulations of future conditions project increases in temperature and extreme precipitation for both lower and higher scenarios (RCP4.5 and RCP8.5; see Figure 19.5).[13,19] After the middle of the 21st century, however, the projected increases are lower for the lower scenario (RCP4.5). Much larger changes are simulated by the late 21st century under the higher scenario (RCP8.5), which most closely tracks with our current consumption of fossil fuels. Under the higher scenario, nighttime

minimum temperatures above 75°F and daytime maximum temperatures above 95°F become the summer norm and nights above 80°F and days above 100°F, now relatively rare occurrences, become commonplace. Cooling degree days (a measure of the need for air conditioning [cooling] based on daily average temperatures rising above a standard temperature—often 65°F) nearly double, while heating degree days (a measure of the need for heating) decrease by over a third (Figure 19.22). The freeze-free season lengthens by more than a month, and the frequency of freezing temperatures decreases substantially.[20,21]

Key Message 1

Urban Infrastructure and Health Risks

Many southeastern cities are particularly vulnerable to climate change compared to cities in other regions, with expected impacts to infrastructure and human health. The vibrancy and viability of these metropolitan areas, including the people and critical regional resources located in them, are increasingly at risk due to heat, flooding, and vector-borne disease brought about by a changing climate. Many of these urban areas are rapidly growing and offer opportunities to adopt effective adaptation efforts to prevent future negative impacts of climate change.

Rapid Population Shifts and Climate Impacts on Urban Areas

While the Southeast is historically known for having a rural nature, a drastic shift toward a more urbanized region is underway. The Southeast contains many of the fastest-growing urban areas in the country, including a dozen of the top 20 fastest-growing metropolitan areas (by percentage) in 2016.[22] Metropolitan Atlanta has been swiftly growing, adding 69,200 residents in just one year.[23] At the same time, many rural counties in the South are losing population.[24] These trends towards a more urbanized and dense Southeast are expected to continue, creating new climate vulnerabilities but also opportunities to adapt as capacity and resources increase in cities (Ch. 17: Complex Systems). In particular, coastal cities in the Southeast face multiple climate risks, and many planning efforts are underway in these cities. Adaptation, mitigation, and planning efforts are emphasizing "co-benefits" (positive benefits related to the reduction of greenhouse gases or implementation of adaptation efforts) to help boost the economy while protecting people and infrastructure.

Increasing Heat

Cities across the Southeast are experiencing more and longer summer heat waves. Nationally, there are only five large cities that have increasing trends exceeding the national average for all aspects of heat waves (timing, frequency, intensity, and duration), and three of these cities are in the Southeast region—Birmingham, New Orleans, and Raleigh. Sixty-one percent of major Southeast cities are exhibiting some aspects of worsening heat waves, which is a higher percentage than any other region of the country.[12] The urban heat island effect (cities that are warmer than surrounding rural areas, especially at night) adds to the impact of heat waves in cities (Ch. 5: Land Changes, KM 1). Southeastern cities including Memphis and Raleigh have a particularly high future heat risk.[25]

The number of days with high minimum temperatures (nighttime temperatures that stay above 75°F) has been increasing across the Southeast (Figure 19.1), and this trend is projected to intensify, with some areas experiencing more than 100 additional warm nights per year by the end of the century (Figures 19.4 and 19.5). Exposure to high nighttime minimum temperatures reduces the ability of some people to recover from high daytime temperatures, resulting in heat-related illness and death.[26] This effect is particularly pronounced in cities, many of which have urban heat islands that already cause elevated nighttime temperatures.[27] Cities are taking steps to prevent negative health impacts from heat. For example, the Louisville, Kentucky, metro government conducted an urban heat management study and installed 145,000 square feet of cool roofs as part of their goal to lessen the risk of climate change impacts.[28]

Historical Number of Warm Nights

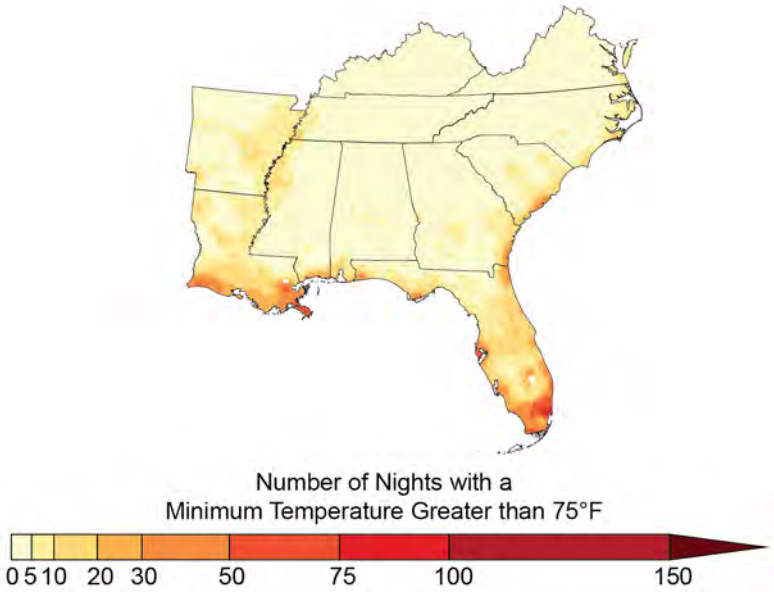


Figure 19.4: The map shows the historical number of warm nights (days with minimum temperatures above 75°F) per year in the Southeast, based on model simulations averaged over the period 1976–2005. Sources: NOAA NCEI and CICS-NC.

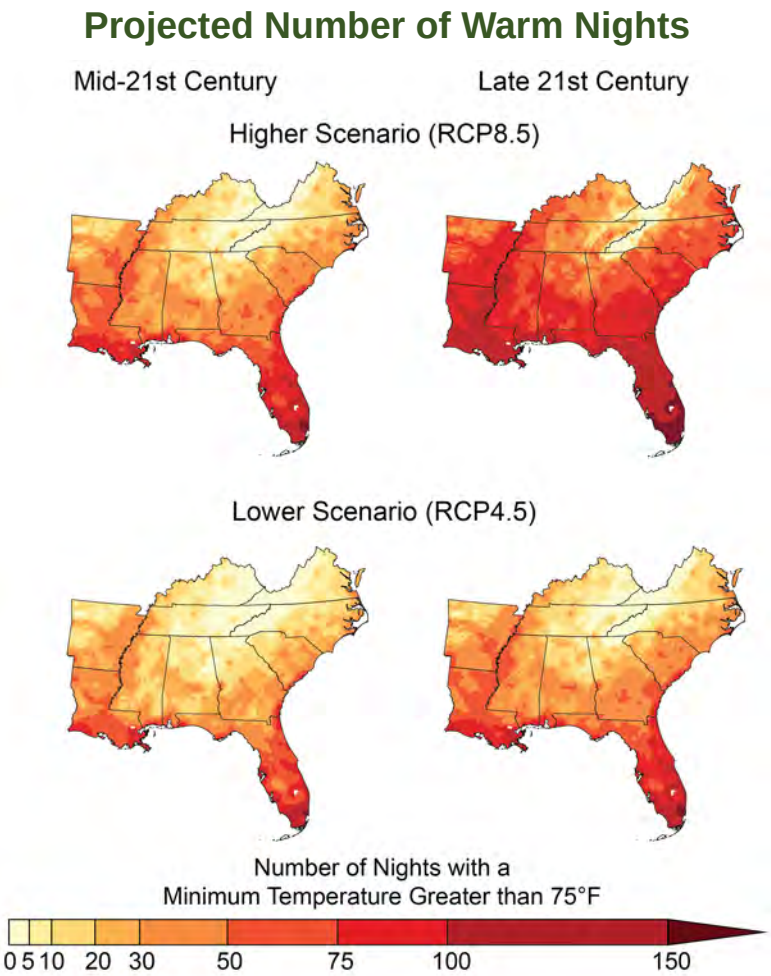


Figure 19.5: The maps show the projected number of warm nights (days with minimum temperatures above 75°F) per year in the Southeast for the mid-21st century (left; 2036–2065) and the late 21st century (right; 2070–2099) under a higher scenario (RCP8.5; top row) and a lower scenario (RCP4.5; bottom row). These warm nights currently occur only a few times per year across most of the region (Figure 19.4) but are expected to become common events across much of the Southeast under a higher scenario. Increases in the number of warm nights adversely affect agriculture and reduce the ability of some people to recover from high daytime temperatures. With more heat waves expected, there will likely be a higher risk for more heat-related illness and deaths. Sources: NOAA NCEI and CICS-NC.

Vector-Borne Disease

The transmission of vector-borne diseases, which are spread by the bite of an animal such as a mosquito or tick, is complex and depends on a number of factors, including weather and climate, vegetation, animal host populations, and human activities (Ch. 14: Human Health, KM 1). Climate change is likely to modify the seasonality, distribution, and prevalence of vector-borne diseases in the Southeast.[29] Vector-borne diseases pose a greater risk in cities than in rural areas because of higher population densities and other human factors (for example, pools of standing water in man-made structures, such as tires or buckets, are breeding grounds for some species of mosquitoes). Climatic conditions are currently suitable for adult mosquitoes of the species *Aedes aegypti*, which can spread dengue, chikungunya, and Zika viruses, across most of the Southeast from July through September (Figure 19.6), and cities in South Florida already have suitable conditions for year-round mosquito activity. The Southeast is the region of the country with the most favorable conditions for this mosquito and thus faces the greatest threat from diseases the mosquito carries.[30] Climate change is expected to make conditions more suitable for transmission of certain vector-borne diseases, including year-round transmission in southern

Florida. Summer increases in dengue cases are expected across every state in the Southeast. Despite warming, low winter temperatures may prevent permanent year-round establishment of the virus across the region.[31] Strategies such as management of urban wetlands have resulted in lower dengue fever risk in Puerto Rico.[32] Similar adaptation strategies have the potential to limit vector-borne disease in southeastern cities, particularly those cities with characteristics similar to Caribbean cities that have already implemented vector control strategies (Ch. 20: U.S. Caribbean).[33,34] The Southeast is also the region with the greatest projected increase in cases of West Nile neuroinvasive disease under both a lower and higher scenario (RCP4.5 and RCP8.5).[35,36]

Air Quality and Human Health

Poor air quality directly impacts human health, resulting in respiratory disease and other ailments. In the Southeast, poor air quality can result from emissions (mostly from vehicles and power plants), wildfires, and allergens such as pollen. The major urban centers in the Southeast are already impacted by poor air quality during warmer months. The Southeast has more days with stagnant air masses than other regions of the country (40% of summer days) and higher levels of fine (small) particulate matter ($PM_{2.5}$), which cause heart and lung disease.[37] There is mixed evidence on the future health impacts of these pollutants. Ozone concentrations would be expected to increase under higher temperatures; however, a variety of factors complicate projections (Ch. 13: Air Quality, KM 1). There are many possible future wind and cloud cover conditions for the Southeast as well as the potential for continued shifts in land-use patterns, demographics and population geography, and vehicle and power plant emissions standards. Increases in precipitation and shifts in wind trajectories may reduce future health impacts of ground level ozone in the Southeast,[35] but warmer and drier autumns are expected to result in a lengthening of the period of ozone exposure.[38] Warmer August temperatures in the Southeast from 1988 to 2011 were associated with increased human sensitivity to ground-level ozone.[39]

The fast growth rate of urban areas in the Southeast contributes to aeroallergens, which are known to cause and exacerbate respiratory diseases such as asthma. Urban areas have higher concentrations of CO_2, which causes allergenic plants, such as ragweed, to grow faster and produce more pollen than in rural areas.[40] Continued rising temperatures and atmospheric CO_2 levels are projected to further contribute to aeroallergens in cities (Ch. 13: Air Quality, KM 3).

Potential Abundance of Disease-Carrying Mosquito

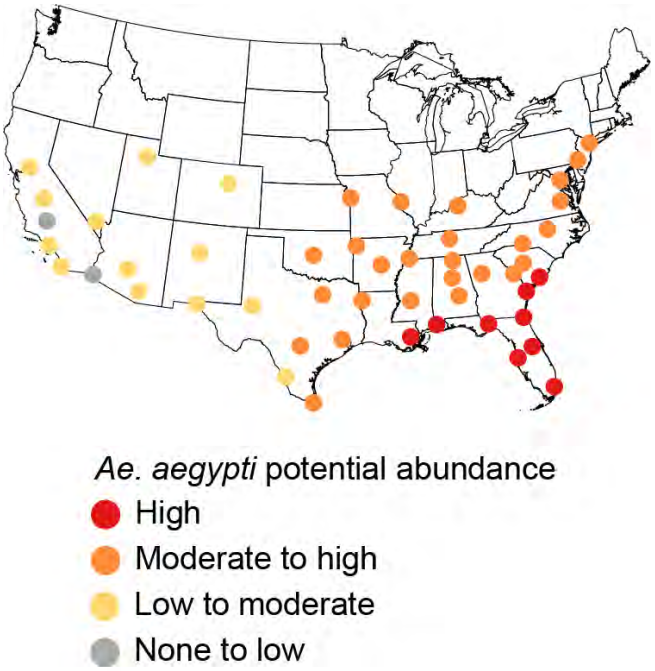


Figure 19.6: The map shows current suitability for the *Aedes aegypti* mosquito in July in 50 different cities. *Aedes aegypti* mosquitoes can spread several important diseases, including dengue fever, chikungunya, and Zika fever. The Southeast is the region of the country with the greatest potential mosquito activity. Warming temperatures have the potential to expand mosquito habitat and disease risk. Source: adapted from Monaghan et al. 2016.[30]

Infrastructure

Infrastructure, particularly roads, bridges, coastal properties, and urban drainage, is vulnerable to climate change and climate-related events (see Key Message 2) (see also Ch. 3: Water, KM 2; Ch. 11: Urban, KM 2; Ch. 12: Transportation, KM 1).[41] By 2050, the Southeast is the region expected to have the most vulnerable bridges.[35] An extreme weather vulnerability assessment conducted by the Tennessee Department of Transportation found that the urban areas of Memphis and Nashville had the most at-risk transportation infrastructure in the state.[42] Increasing precipitation and extreme weather events will likely impact roads, freight rail, and passenger rail, especially in Memphis, which will likely have cascading effects across the region.[43] Transit infrastructure, such as the rail lines of the Metropolitan Atlanta Rapid Transit Authority (MARTA), are also at risk. As a result, MARTA has begun to identify vulnerable assets and prioritize improvements to develop a more resilient system.[44]

Many cities across the Southeast are planning for the impacts sea level rise is likely to have on their infrastructure (see Case Study "Charleston, South Carolina, Begins Planning and Reinvesting" and Key Message 2). Flood events in Charleston, South Carolina, have been increasing, and by 2045 the city is projected to face nearly 180 tidal floods (flooding in coastal areas at high tide) per year, as compared to 11 floods per year in 2014.[45] These floods affect tourism, transportation, and the economy as a whole. The city has responded by making physical modifications, developing a more robust disaster response plan, and improving planning and monitoring prior to flood events.

Infrastructure related to drinking water treatment and wastewater treatment may be compromised by climate-related events (Ch. 3: Water, KM 2). Water utilities across the Southeast are preparing for these impacts. Tampa Bay Water, the largest wholesale water utility in the Southeast, is coordinating with groups including the Florida Water and Climate Alliance to study the impact of climate change on its ability to provide clean water in the future.[46,47] Spartanburg Water, in South Carolina, is reinforcing the ability of the utility to "cope with, and recover from disruption, trends and variability in order to maintain services."[48] Similarly, the Seminole Tribe of Florida, which provides drinking and wastewater services, assessed flooding and sea level rise threats to their water infrastructure and developed potential adaptation measures.[49] The development of "green" water infrastructure (using natural hydrologic features to manage water and provide environmental and community benefits), such as the strategies promoted in the City of Atlanta Climate Action Plan, is one way to adapt to future water management needs. Implementation of these strategies has already resulted in a reduction in water consumption in the city of Atlanta, relieving strain on the water utility and increasing resilience.[50]

There are still gaps in knowledge regarding the potential effects of climate change on cities across the Southeast. Cross-disciplinary groups such as the Georgia Climate Project (http://www.georgiaclimateproject.org) are developing research roadmaps that can help to prioritize research and action with relevance to policymakers, practitioners, and scientists.

Key Message 2

Increasing Flood Risks in Coastal and Low-Lying Regions

The Southeast's coastal plain and inland low-lying regions support a rapidly growing population, a tourism economy, critical industries, and important cultural resources that are highly vulnerable to climate change impacts. The combined effects of changing extreme rainfall events and sea level rise are already increasing flood frequencies, which impacts property values and infrastructure viability, particularly in coastal cities. Without significant adaptation measures, these regions are projected to experience daily high tide flooding by the end of the century.

Sea Level Rise Is Contributing to Increased Coastal Flooding in the Southeast

Average global sea level (or global mean sea level; GMSL) has risen about 8–9 inches since 1880, with about 3 inches of that rise occurring since 1990.[51,52] This recent increase in the rate of rise is projected to accelerate in the future due to continuing temperature increases and additional melting of land ice.[51] This recent global rate increase, combined with the local effects of vertical land motion (sinking) and oceanographic effects such as changing ocean currents, has caused some areas in the Southeast to experience even higher local rates of sea level rise than the global average.[53,54,55,56,57,58,59] Analyses at National Oceanic and Atmospheric Administration (NOAA) tide gauges show as much as 1 to 3 feet of local relative sea level rise in the past 100 years in low-lying areas of the Southeast.[54,59] This recent rise in local relative sea level has caused normal high tides to reach critical levels that result in flooding in many coastal areas in the region.

Monthly and seasonal fluctuations in high tide levels are caused by a combination of astronomical factors (sun and moon gravitational attraction) and non-astronomical factors such as geomorphology (landscape of the area), as well as meteorological (weather) conditions. The highest tides of the year are generally the perigean, or spring, tides, which occur when the moon is full or new and is closest to the Earth. These perigean tides, also known as "king tides," occur twice a year and in many cities are causing what has been called "nuisance" or "recurrent" flooding (referred to herein as high tide flooding). These floods can cause problems ranging from inconvenient to life changing. While the challenges brought on by rising perigean tides are diverse, important examples include increasingly frequent road closures, excessive water in storm water management systems, and deterioration of infrastructure such as roads and rail from saltwater. NOAA's National Weather Service (NWS) issues coastal flood advisories and warnings when water levels at tide gauges are expected to exceed flood thresholds. These thresholds correspond to discrete water levels relative to NOAA tide gauges.

Recent analyses of historical water levels at many NOAA tide gauges has shown an increase in the number of times that these warning thresholds were exceeded compared to the past. Annual occurrences of high tide coastal flooding have increased 5- to 10-fold since the 1960s in several low-lying coastal cities in the Southeast (Figure 19.7).[51,60] In 2015, several Southeast coastal cities experienced all-time records of coastal flooding occurrences, including Wilmington, NC (90 days), Charleston, SC (38 days), Mayport, FL (19 days), Miami, FL (18 days), Key West, FL (14 days), and Fernandina Beach, FL (7 days). These flooding occurrences increased more than 50% in 2015 compared to 2014.[58] In 2016, three all-time records were either tied (14 days at Key West,

FL) or broken (50 days at Charleston, SC, and 38 days at Savannah, GA). The Miami area nearly matched the 2015 record of 18 days.[61] This increase in high tide flooding frequency is directly tied to sea level rise. For example, in Norfolk, Virginia, local relative sea level rise has led to a fourfold increase in the probability of exceeding NWS thresholds compared to the 1960s (Figure 19.8). High tide flooding is now posing daily risks to businesses, neighborhoods, infrastructure, transportation, and ecosystems in the Southeast.[1,2]

Global sea level is very likely to rise by 0.3–0.6 feet by 2030, 0.5–1.2 feet by 2050, and 1.0–4.3 feet by 2100 under a range of scenarios from very low (RCP2.6) to high (RCP8.5),[51,52,62] which would result in increases in both the depth and frequency of coastal flooding (Figure 19.7).[51] Under higher emissions scenarios (RCP8.5), global sea level rise exceeding 8 feet (and even higher in the Southeast) by 2100 cannot be ruled out.[51] By 2050, many Southeast cities are projected to experience more than 30 days of high tide flooding regardless of scenario.[63] In addition, more extreme coastal flood events are also projected to increase in frequency and duration.[60] For example, water levels that currently have a 1% chance of occurring each year (known as a 100-year event) will be more frequent with sea level rise. This increase in flood frequency suggests the need to consider revising flood study techniques and standards that are currently used to design and build coastal infrastructure.

Higher sea levels will cause the storm surges from tropical storms to travel farther inland than in the past, impacting more coastal properties. The combined impacts of sea level rise and storm surge in the Southeast have the potential to cost up to $60 billion each year in 2050 and up to $99 billion in 2090 under a higher scenario (RCP8.5).[35] Even under a lower scenario (RCP4.5), projected damages are $56 and $79 billion in 2050 and 2090, respectively (in 2015 dollars, undiscounted).[35] Florida alone is estimated to have a 1-in-20 chance of having more than $346 billion (in 2011 dollars) in property value (8.7%) below average sea level by 2100 under a higher scenario (RCP8.5).[64] An assessment by the Florida Department of Health determined that 590,000 people in South Florida face “extreme” or “high” risk from sea level rise, with 125,000 people living in these areas identified as socially vulnerable and 55,000 classified as medically vulnerable.[65] In addition to causing direct injury, storm surge and related flooding can impact transportation infrastructure by blocking or flooding roads and affecting access to healthcare facilities (Ch. 12: Transportation, KM 1). Marine transportation can be impacted as well. Large ports in the Southeast, such as Charleston, Savannah, and Jacksonville, and the rails and roads that link to them, are particularly vulnerable to both coastal flooding and sea level rise (Ch. 12: Transportation, KM 1; Ch. 8: Coastal, KM 1). The Port of Jacksonville provides raw material for industries, food, clothes, and essential goods to Puerto Rico, thus impacting the U.S. Caribbean region, as well (Ch. 20: U.S. Caribbean, KM 3). It is estimated that with a meter (about 3.3 feet) of sea level rise, the Southeast would lose over 13,000 recorded historic and prehistoric archaeological sites and more than 1,000 locations currently eligible for inclusion on the National Register of Historic Places.[66] This includes many historic buildings and forts in cities like Charleston, Savannah, and St. Augustine.

Annual Number of High Tide Flooding Days

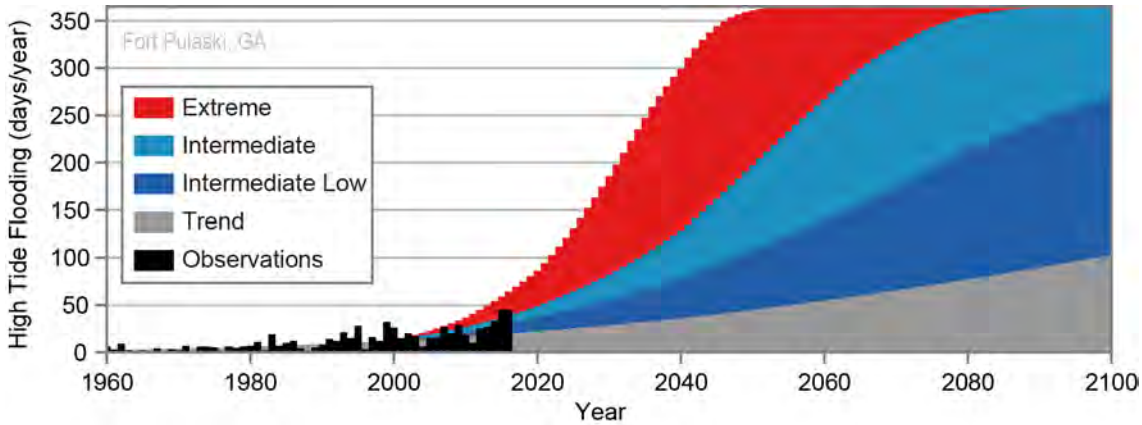


Figure 19.7: The figure shows the annual number of days experiencing high tide floods based on observations for 1960–2016 for Fort Pulaski, near Savannah, Georgia (black), and projected increases in the number of annual flood events based on four future scenarios: a continuation of the current relative sea level trend (gray) and the Intermediate-Low (dark blue), Intermediate (light blue), and Extreme (red) sea level rise scenarios. See Sweet et al. (2017)[51] and Appendix 3: Data & Scenarios for additional information on projection and trend data. Source: adapted from Sweet and Park 2014.[63]

Range of Daily Highest Water Levels in Norfolk, Virginia

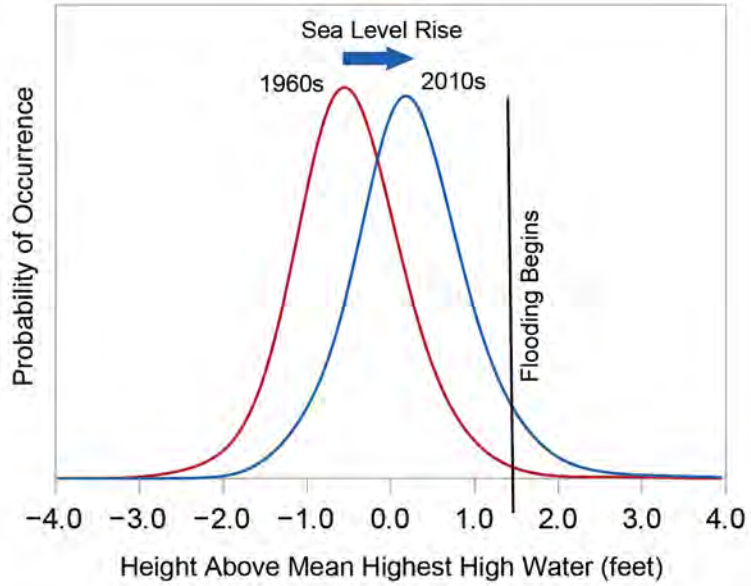


Figure 19.8: The curves in this figure show a range of daily Mean Higher High Water (MHHW) levels in Norfolk, Virginia (Sewells Point), for the 1960s and 2010s. Local sea level rise has shifted the curve closer to the point where high tide flooding begins (based on warning thresholds established by the National Weather Service). This shows why many more high tide flood events occur now than they did in the past (increase of 6 flood days per year). Source: adapted from Sweet et al. 2017.[52]

Case Study: Charleston, South Carolina, Begins Planning and Reinvesting for Sea Level Rise

The main crosstown traffic artery in Charleston, South Carolina (U.S. 17 Septima Clark Parkway–crosstown), has historically been susceptible to flooding events (Figure 19.9). Charleston experienced all-time record high tide flood occurrences in 2015 (38 days) and 2016 (50 days).[52,58] By 2045, Charleston is projected to experience up to 180 high tide flood events a year.[1] The City of Charleston estimated that each flood event that affects the crosstown costs $12.4 million (in 2009 dollars). Over the past 50 years, the resultant gross damage and lost wages have totaled more than $1.53 billion (dollar year not specified). As a result, Charleston has developed a Sea Level Rise Strategy that plans for 50 years out based on moderate sea level rise scenarios (Figure 19.10) and that reinvests in infrastructure, develops a response plan, and increases readiness.[45] As of 2016, the City of Charleston has spent or set aside $235 million (in 2015 dollars) to complete ongoing drainage improvement projects (Figure 19.9) to prevent current and future flooding.

Figure 19.9: (left) U.S. Highway 17 (Septima Clark Parkway—crosstown) in Charleston, South Carolina, during a flood event. Floodwaters can get deep enough to stall vehicles. (right) Market Street drainage tunnel being constructed in Charleston, South Carolina, as part of a drainage improvement project to prevent current and future flooding. This tunnel crosses a portion of downtown Charleston 140 feet underground and is designed to rapidly convey storm water to the nearby Ashley River. Photo credit: City of Charleston 2015.[45]

Projected Sea Level Rise for Charleston, South Carolina

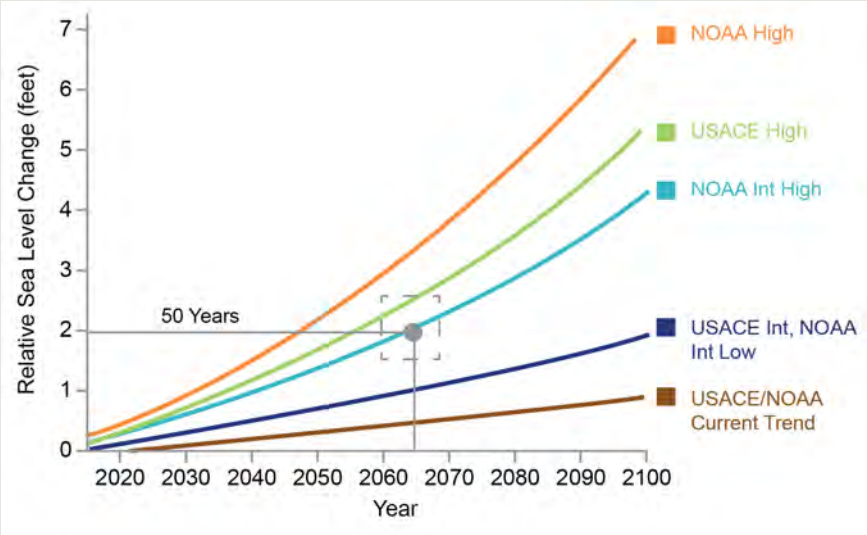


Figure 19.10: The City of Charleston Sea Level Rise Strategy calls for a 50-year outlook, based on existing federal sea level change projections in 2015 (colored curves), and calls for using a range of 1.5–2.5 feet of sea level rise (dashed box). A 1.5-foot increase will be used for short-term, less vulnerable investments, such as a parking lot. A 2.5-foot increase will be used for critical, longer-term investments, such as emergency routes and public buildings. This 1-foot range was chosen to approximate the average of these projections in 2065. Source: City of Charleston 2015.[45]

Many of the older historical coastal cities in the Southeast were built just above the current Mean Higher High Water (MHHW) level (the average height of the higher of the two daily high tides at a given location), with a gravity-driven drainage system designed to drain rainwater into the tidal estuaries. As sea levels have risen locally in the last one hundred years, the storm water systems in these areas are no longer able to perform as designed. When these cities experience high tide coastal flooding due to perigean tides, the tidewater enters the storm water system, which prevents rainwater from entering storm drains and causes increased impacts from flooding. In the future, the gravity-driven nature of many of these systems may cease to function as designed, causing rainwater to flood streets and neighborhoods until the tide lowers and water can drain normally. Cities such as Charleston and Miami have already begun to improve storm water infrastructure and explore natural and nature-based infrastructure design to reduce future flood risk.

Much of the Southeast region's coast is bordered by large expanses of salt marsh and barrier islands. Long causeways with intermittent bridges to connect the mainland to these popular tourism destinations were built decades ago at only a few feet above MHHW. Sea level rise has put these transportation connection points at risk. High tide coastal flooding has started to inundate these low-lying roads, restricting access during certain times of the day and causing public safety concerns. The U.S. East Coast, for example, already has 7,508 miles of roadways, including over 400 miles of interstate roadways, currently threatened by high tide coastal flooding (Ch. 12: Transportation, KM 1 and Figure 12.2).

Sea level rise is already causing an increase in high tide flood events in the Southeast region and is adding to the impact of more extreme coastal flooding events. In the future, this flooding is projected to become more serious, disruptive, and costly as its frequency, depth, and inland extent grow with time (Ch. 12: Transportation, KM 1).[52,63,67,68]

Case Study: A Lesson Learned for Community Resettlement: Isle de Jean Charles Band of Biloxi-Chitimacha-Choctaw Tribe

Coastal communities in the Southeast are already experiencing impacts from higher temperatures, sea level rise, increased flooding, and extreme weather events.[69,70,71,72] Several communities in the United States are already discussing the complexities of relocation; most are tribal and Indigenous communities.[73] Some have chosen to stay in their homelands, while others have few options but to relocate (Ch. 15: Tribes, KM 3).

Isle de Jean Charles is a narrow island in the bayous of South Terrebonne Parish, Louisiana, and home to the Isle de Jean Charles Band of Biloxi-Chitimacha-Choctaw, a tribal community already living the day-to-day impacts of land loss, sea level rise, and coastal flooding. The island has lost 98% of its landmass since 1955 and has only approximately 320 acres (approximately 1/2 square mile) remaining. The population living on the Island has fallen from 400 to 85 people. The decline is due in large part to land loss and flooding driven by climate change, extreme weather, and unsustainable development practices, which stem from oil and gas production, extraction, and water-management practices.[74] This process has resulted in family separation, spreading them across southern Louisiana.[75] In addition, the Tribe continues to lose parts of its livelihood and culture, including sacred places, cultural sites and practices, healing plants, traditional foods, and lifeways.[76]

Case Study: A Lesson Learned for Community Resettlement: Isle de Jean Charles Band of Biloxi-Chitimacha-Choctaw Tribe, *continued*

The Third National Climate Assessment[77] discussed the initial plans for resettlement of the Isle de Jean Charles community. Recently, after nearly 20 years of tribal persistence and two previous efforts, the U.S. Department of Housing and Urban Development (HUD) through the National Disaster Resilience Competition,[78] along with technical assistance from The Rockefeller Foundation, awarded the State of Louisiana $48 million (in 2016 dollars) to implement the Tribe's resettlement plan: a community-driven, culturally appropriate, sustainable development-based plan. It was developed in partnership with the Lowlander Center, a local nongovernmental organization with a long-standing relationship with the Tribe and other scientists, researchers, and planners. The award provides the Tribe with a historic opportunity to reunite a community.[79] While the application to relocate was initiated by the Tribe, the relocation funds now are for all residents of Isle de Jean Charles, according to the Louisiana State Office of Community Development.[75]

Figure 19.11: Chantel Comardelle, Isle de Jean Charles Tribe's Executive Secretary, leads a discussion at a community meeting for the Tribe's resettlement planning process in Pointe-aux-Chenes, Louisiana, on January 18, 2016. The meeting was supported by the Lowlander Center. Photo credit: The Lowlander Center Team.

The resettlement plan is expected to be implemented by 2022 with the inclusion of many facilities in the new location to revitalize the tribal community, including a tribal center and a healthcare facility. The Tribe's experience highlights how success can be achieved when at-risk communities are engaged in the resettlement planning process from the beginning to ensure long-term successful relocation and maintain community integrity.[80] It also highlights an opportunity for institutions to evolve in more flexible ways to accommodate the growing number of communities that may need to relocate.

Extreme Rainfall Events Are Contributing to Increased Inland and Coastal Flooding

Extreme rainfall events have increased in frequency and intensity in the Southeast, and there is *high confidence* they will continue to increase in the future (Figure 19.3).[19] The region, as a whole, has experienced increases in the number of days with more than 3 inches of precipitation (Figure 19.3) and a 16% increase in observed 5-year maximum daily precipitation (the amount falling in an event expected to occur only once every 5 years).[19] Both the frequency and severity of extreme precipitation events are projected to continue increasing in the region under both lower and higher scenarios (RCP4.5 and RCP8.5). By the end of the century under a higher scenario (RCP8.5), projections indicate approximately double the number of heavy rainfall events (2-day precipitation events with a 5-year return period) and a 21% increase in the amount of rain falling on the heaviest precipitation days (days with a 20-year return period).[19,81] These projected increases would directly affect the vulnerability of the Southeast's coastal and low-lying areas. Natural resources (see Key Message 3),

industry, the local economy, and the population of the region are at increasing risk to these extreme events.

Across the Southeast since 2014, there have been numerous examples of intense rainfall events—many approaching levels that would be expected to occur only once every 500 years[82,83]—that have made state or national news due to the devastating impact they had on inland communities. Of these events, four major inland flood events have occurred in just three years (2014–2016) in the Southeast, causing billions of dollars in damages and loss of life (see Table 19.1 and Case Study "Coastal and Inland Impacts of Extreme Rainfall").[84]

A closer look at the August 2016 event in Louisiana provides an example of how vulnerable inland communities in the Southeast region are to these extreme rainfall events. Between August 11–15 2016, nearly half of southern Louisiana received at least 12–14 inches of rainfall. While urban areas such as Baton Rouge and Lafayette were hit the hardest, receiving upwards of 30 inches in a few days, coastal locations were also inundated with up to 20 inches of rain. Rainfall totals across the region exceeded amounts that would be expected to occur once every 1,000 years (or a less than 0.1% annual probability of occurrence), causing the Amite and Comite Rivers to surge past their banks and resulting in some 50,000 homes across the region filling with more than 18 inches of water.[85] Nearly 10 times the number of homes received major flooding (18 inches or more) during this event compared to a historic 1983 flood in Baton Rouge, and the damage resulted in more than 2 million cubic yards of curbside debris from cleaning up homes (enough to fill over 600 Olympic-sized pools).[86] A preceding event in northern Louisiana on March 8–12, 2016, caused $2.4 billion in damages (in 2017 dollars; $2.3 billion in 2015 dollars) and five casualties,[84] illustrating that inland low-lying areas in the Southeast region are also vulnerable to flooding impacts. Events of such magnitudes are projected to become more likely in the future due to a changing climate,[19,87] putting more people in peril from future floods. Existing flood map boundaries do not account for future flood risk due to the increasing frequency of more intense precipitation events, as well as new development that would reduce the floodplain's ability to manage storm water. As building and rebuilding in flood-prone areas continue, the risks of the kinds of major losses seen in these events will continue to grow.

The growing number of extreme rainfall events is stressing the deteriorating infrastructure in the Southeast. Many transportation and storm water systems have not been designed to withstand these events. The combined effects of rising numbers of high tide flooding and extreme rainfall events, along with deteriorating storm water infrastructure, are increasing the frequency and magnitude of coastal and lowland flood events.[45,88,89,90]

Billion-Dollar Flood Events in the Southeast, 2014–2016

Event	Date	Damages	Casualties
Southeast tornadoes and flooding (FL, AL, AR)	April 27–28, 2014	$1.8 Billion	33
South Carolina record flooding	October 1–5, 2015	$2.1 Billion	25
Hurricane Matthew	October 7–9, 2016	$10.1 Billion	49
Louisiana flooding (Baton Rouge)	August 11–15, 2016	$10.1 Billion	13

Table 19.1: Values are Consumer Price Index adjusted and are in 2017 dollars. Source: NOAA NCEI 2017.[84]

The recent increases in flood risk have led many cities and counties to take adaptive actions to reduce these effects. Four counties in Southeast Florida formed a climate compact in 2010 to address climate change impacts, including sea level rise and high tide flooding.[91] Recently updated in 2017, their climate action plan was one of the first intergovernmental collaborations to address climate change, adaptation, and mitigation in the country. Since then, cities like Charleston, South Carolina, have started to invest in flood management activities (see Case Study "Charleston, South Carolina, Begins Planning and Reinvesting"). Other examples include Miami Beach, Florida, which has a multiyear, $500-million program to raise public roads and seawalls and improve storm water drainage.[92] Norfolk, Virginia, has begun comprehensive planning to fix its high tide flooding issues.[93] Biloxi, Mississippi, has put in place several adaptation strategies to lessen the future impacts, including enacting a new building code that requires elevating structures an additional one foot above the base flood elevation.[94] Tybee Island, Georgia, has developed a sea level rise adaptation plan with recommendations to flood-proof a 5.5-mile stretch of their sole access causeway, replace two vulnerable bridges, and retrofit their existing storm water infrastructure to improve drainage.[95] In response to the 2016 flooding, eight parishes in the Acadiana region of Louisiana came together to collaborate at a watershed level, pooling their federal hazard mitigation grant funding to support projects across the Teche-Vermilion watershed. This is the only watershed-level hazard mitigation collaboration of this kind happening in the state and has the support of the Federal Emergency Management Agency (FEMA), the Governor's Office of Homeland Security and Emergency Preparedness, and the Louisiana Office of Community Development.[96]

Many communities in the Southeast also participate in FEMA's Community Rating System (CRS) program, which provides reduced flood insurance premiums to communities that go above and beyond the minimum National Flood Insurance Program regulation standards.[97] Many communities require a safety factor, also known as freeboard, expressed as feet above the base flood elevation, for construction in special flood hazard areas. Several Southeast communities—such as Hillsborough and Pinellas Counties, Florida; Biloxi, Mississippi; Chatham County, Georgia; and Myrtle Beach, South Carolina—have earned low CRS classes (5 on a scale of 1–10, with 1 being the best or most insurance premium discount) by implementing freeboard and other regulations that exceed the minimum standards.[97]

Case Study: Coastal and Inland Impacts of Extreme Rainfall

In October 2015, an extreme rainfall event impacted both inland and coastal South Carolina, leading to the largest flood-related disaster in the state since Hurricane Hugo struck in 1989. The October 2015 event is among a series of devastating precipitation events that have occurred across the Southeast in recent years. From October 1–5, 2015, deep tropical moisture combined with a slow-moving (stalled) upper-level low pressure system to pump moisture into South Carolina's coastal and interior regions. Much of the affected region received between 10 and 26 inches of rain over the 4-day event, breaking many all-time precipitation records (Figure 19.12). Mount Pleasant, located on South Carolina's coast, received 26.88 inches of rain, which is an extremely rare event. The rainfall sparked inland flooding that led to three dam breaches and the destruction of countless roads and homes (see Figure 19.13 showing flash flooding impacts to inland roads). Roughly 52,000 residents applied for disaster relief, and 160,000 homes sustained some type of damage. At the coast, a combination of high tide and heavy rain caused significant flooding in downtown Charleston. A high tide of 2.38 feet above Mean Higher High Water (MHHW) occurred in the afternoon of October 3. This was the seventh highest tide ever recorded in Charleston Harbor and the highest since Hurricane Hugo in 1989. Under future climate scenarios, the combination of extreme precipitation and higher tides due to local sea level rise will likely cause more frequent events of this intensity and magnitude.[98]

Case Study: Coastal and Inland Impacts of Extreme Rainfall, *continued*

October 2015 Extreme Rainfall Event

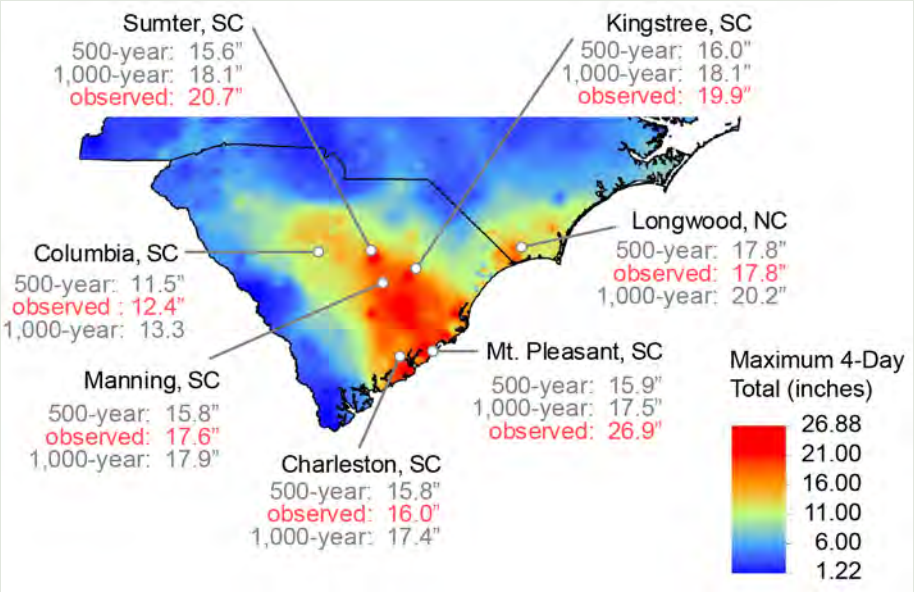


Figure 19.12: The map shows rainfall totals from the October 2015 South Carolina flood event. Red colors in the map indicate areas that received excessive rainfall totals that broke all-time records. Some of these totals exceeded the 500-year and 1,000-year return period amounts (rainfall amounts that would be expected to have only a 0.2% or 0.1% chance of occurring in a given year). Extreme precipitation events will likely increase in frequency in the Southeast. Source: CISA 2015.[98]

Figure 19.13: Many roads became impassable in the inland areas of South Carolina as a result of the October 2015 extreme rainfall event. This photo shows a neighborhood in North Charleston after the event with knee-deep flooding. Photo credit: Ryan Johnson (CC BY-SA 2.0).

Increases in extreme rainfall events and high tide coastal floods due to future climate change could impact the quality of life of permanent residents as well as tourists visiting the low-lying and coastal regions of the Southeast. Recent social science studies have indicated that people may migrate from many coastal communities that are vulnerable to the impacts of sea level rise, high tide flooding, saltwater intrusion, and storm surge.[71] Even though many communities are starting to develop adaptation strategies to address current flooding issues, many adaptation strategies are not being designed for longer time horizons and more extreme worst-case climate scenarios.[1,67]

The 2017 Hurricane Season

For the United States, 2017 was a historic year for weather and climate disasters, with widespread impacts and lingering costs. While 2017 tied the previous record year of 2011 for the total number of billion-dollar weather and climate disasters—16—the year broke the all-time previous record high costs by reaching $306.2 billion in damages (in 2017 dollars; $297 billion in 2015 dollars). The previous record year was 2005 with a total of $214.8 billion (in 2017 dollars; $208.4 billion in 2015 dollars), which included the impacts of Hurricanes Dennis, Katrina, Rita, and Wilma.[99]

In 2017, Hurricane Irma was one of three major hurricanes to make landfall in the United States and territories, with the most significant impacts occurring in the Southeast region. Irma was a Category 4 storm with 130 mph wind speeds when it made landfall at Cudjoe Key, Florida (20 miles north of Key West). Storm surge inundations at Cudjoe and the surrounding Keys were between 5 and 8 feet.[100] Prior to landfall in Florida, Irma caused significant damage in the U.S. Virgin Islands and parts of Puerto Rico as a Category 5 hurricane with 185 mph wind speeds (see Ch. 20: U.S. Caribbean, Box 20.1 and KM 5).[84]

Irma's intensity was impressive by any measure. According to the National Weather Service, Hurricane Irma was only the fifth hurricane with winds of 185 mph or higher in the whole of the Atlantic Basin since reliable record keeping began, and it was the strongest observed hurricane in the open Atlantic Ocean.[101] For three days, the storm maintained maximum sustained winds of 185 miles per hour, the longest observed duration in the satellite era.[101,102] Not only was Irma extremely strong, it was also very large with tropical storm force winds reaching as far away as 400 miles from the hurricane's center and driving hurricane force winds up to 80 miles away.[101] Two factors supported Irma's strength: the very warm waters it passed over, which exceeded 86°F,[102] and the light winds Irma encountered in the upper atmosphere (Figure 19.14).[101] High-intensity hurricanes such as Irma are expected to become more common in the future due to climate change.[103] Rapid intensification of storms is also more likely as the climate warms,[104] even though there is also some historical evidence that the same conditions that lead to this intensification also act to weaken hurricane intensity near the U.S. coast, but it is unclear whether this relationship will continue as the climate warms further (see Kossin et al. 2017,[103] Box 9.1).

The storm tracked up the west coast of Florida, impacting both coasts of the Florida peninsula with 3–5 feet of inundation from Cape Canaveral north to the Florida–Georgia border and even further, impacting coastal areas of Georgia and South Carolina with high tides and storm surge that reached 3–5 feet. Inland areas were also impacted by winds and heavy rains with river gauges and high-water marks showing upwards of 2–6 feet above ground level.[100] The winds eventually fell below tropical storm strength near Columbus, Georgia. Even though the wind speed fell below tropical storm strength, many communities along the coasts of Florida, Georgia,

North and South Carolina, and Virginia experienced severe wind and storm surge damage with some near-historic levels of coastal flooding. A state of emergency was declared in four states from Florida north to Virginia and in Puerto Rico and the U.S. Virgin Islands, and, for the first time ever, Atlanta was placed under a tropical storm warning.[105,106,107,108] In Florida, a record 6.8 million people were ordered to evacuate, as were 540,000 coastal residents in Georgia and untold numbers in other coastal locations.[102,109,110] Nearly 192,000 evacuees were housed in approximately 700 emergency shelters in Florida alone.[109] According to NOAA's National Centers for Environmental Information (NCEI),[84] Irma significantly damaged 65% of the buildings in the Keys and destroyed 25% of them.

Warm Waters Contribute to the Formation of Hurricane Irma

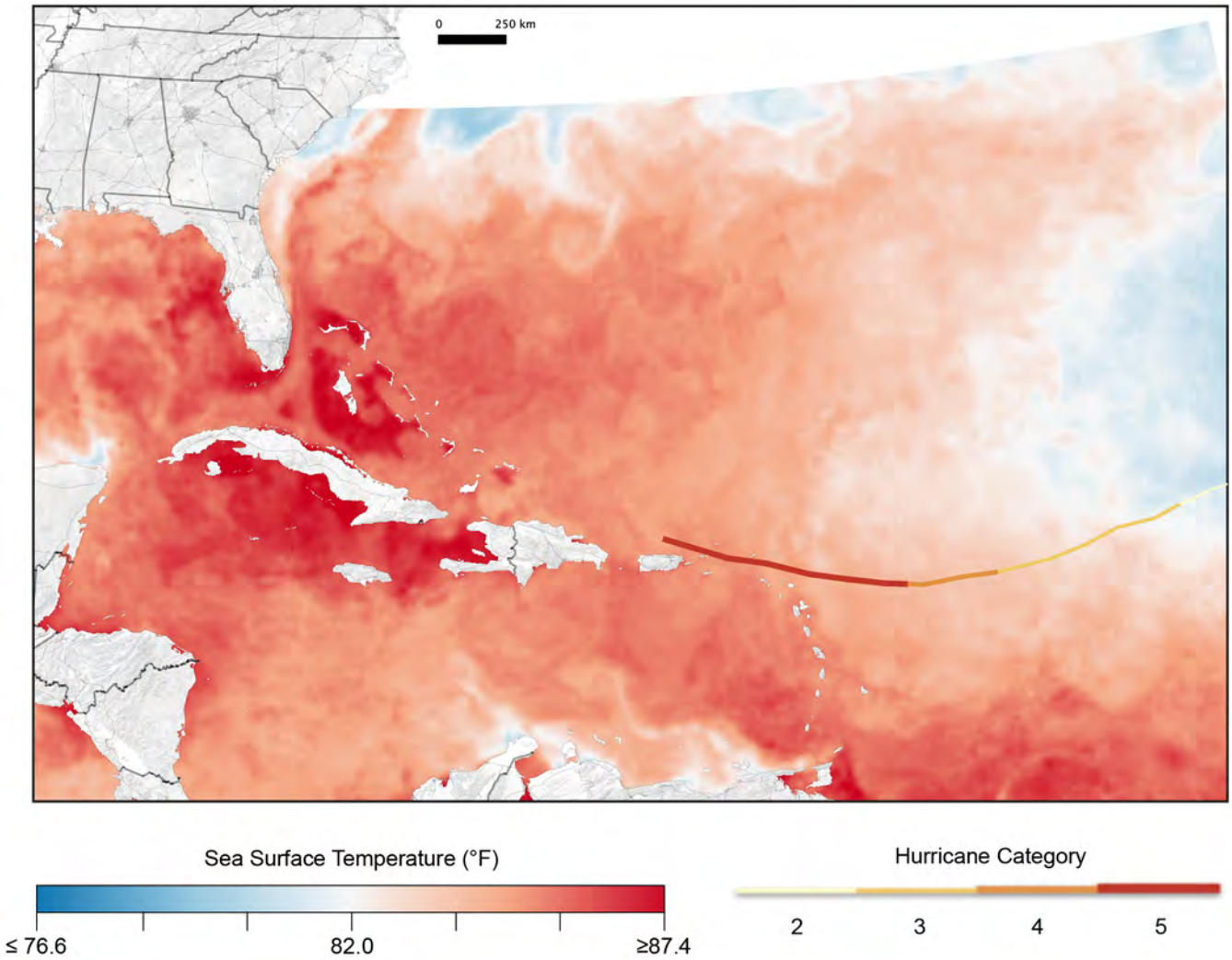


Figure 19.14: Two factors supported Hurricane Irma's strength as it reached the Southeast region: the very warm waters it passed over, depicted in this figure, and the light winds Irma encountered in the upper atmosphere.[101] High-intensity hurricanes such as Irma are expected to become more common in the future due to climate change.[103] Source: NASA 2017.[102]

High rainfall totals were experienced in many impacted areas, with Fort Pierce, Florida, receiving the highest rainfall of more than 21.5 inches[100] and the Florida Keys receiving 12 inches of rain.[84,102] Flooding occurred on most rivers in northern Florida and in many rivers in both Georgia and South Carolina to the point that rescues were required. In Jacksonville, Florida, heavy rains were the major issue causing rivers to reach major or record flood stage and flooded some city streets up to 5 feet deep in water. The heavy rainfall was noted even in Alabama, at 5 inches, and near 6 inches in the mountains of western North Carolina.[100] Twenty-five tornadoes were confirmed from Hurricane Irma, and many of them occurred along the east coast of central and northern Florida.[100] Even as Irma headed north, continuing to lose force, there were still 6.7 million people without electricity.[109]

According to NCEI,[84] the U.S. direct cost from Hurricane Irma is approximately $50 billion (in 2017 dollars), and the non-U.S. territory Caribbean Islands could add another $10–$15 billion to that total. Of the $50 billion, approximately $30–$35 billion accounts for wind and flood damage to a combination of residential and commercial properties, automobiles, and boats—with 80%–90% of this cost felt in Florida. The remainder of the costs include $5 billion for infrastructure repairs and $1.5–$2.0 billion for damage to the agricultural sector, also mainly in Florida. The remaining costs would address losses in the U.S. Virgin Islands and Puerto Rico.[84] The losses could have been worse except for the fact that Florida has implemented one of the strictest building codes in the country after the destruction caused by Hurricane Andrew in 1992.[111] Recent estimates using insured loss data show that implementing the Florida Building Code resulted in a 72% reduction of windstorm losses, and for every $1 in added cost to implement the building code, there is a savings of $6 in reduced losses, with the return or payback period being roughly 8 years (in 2010 dollars).[111]

Indirect impacts and costs are difficult to calculate and would add to the totals. In Central and South Florida, such things would include the closing of schools, colleges, and universities; the closing of tourist attractions and the cancellation of thousands of flights into and out of region; and the closing or restricting of the use of seaports including Canaveral, Key West, Miami, and Jacksonville, among others.[109,112] The Select Committee on Hurricane Response and Preparedness: Final Report[109] estimates that there were 84 U.S. deaths attributable to Hurricane Irma and other untold damage and human suffering. While the hurricane directly damaged portions of the Southeast, the impacts could be felt around the country in the form of business interruptions (such as tourism), transportation and infrastructure damages (such as ports, roadways, and airports), increases in fuel costs, and $2.5 billion (in 2018 dollars) in total estimated crop losses,[109] which had the potential to impact the cost of food and other products for all Americans.

Key Message 3

Natural Ecosystems Will Be Transformed

The Southeast's diverse natural systems, which provide many benefits to society, will be transformed by climate change. Changing winter temperature extremes, wildfire patterns, sea levels, hurricanes, floods, droughts, and warming ocean temperatures are expected to redistribute species and greatly modify ecosystems. As a result, the ecological resources that people depend on for livelihood, protection, and well-being are increasingly at risk, and future generations can expect to experience and interact with natural systems that are much different than those that we see today.

Ecosystems in the Southeast span the transition zone between tropical and temperate climates. The region's more temperate ecosystems include hardwood forests, spruce-fir forests, pine-dominated forests, and salt marshes. The region's more tropical ecosystems include mangrove forests, coral reefs, pine savannas, and the tropical freshwater wetlands of the Everglades. Ecological diversity in the Southeast is high,[113,114,115,116,117] and southeastern ecosystems and landscapes provide many benefits to society. In addition to providing habitat for fish and wildlife species, ecosystems in the Southeast provide recreational opportunities, improve water quality, provide seafood, reduce erosion, provide timber, support food webs, minimize flooding impacts, and support high rates of carbon sequestration (or storage).[118,119,120] These ecological resources that people depend on for livelihoods, protection, and well-being are increasingly at risk from the impacts of climate change.

Climate greatly influences the structure and functioning of all natural systems (Ch. 7: Ecosystems). An analysis of ecological changes that have occurred in the past can help provide some context for anticipating and preparing for future ecological changes. In response to past climatic changes, many ecosystems in the Southeast were much different than those present today. For example, since the end of the last glacial maximum (about 19,000 years ago—the most recent period of maximum ice extent),[121] forests in the region have been transformed by warming temperatures, sea level rise, and glacial retreat.[122,123] Spruce species that were once present in the region's forests have moved northward and have been replaced by oaks and other less cold-tolerant tree species that have expanded from the south.[124] And along the coast, freeze-sensitive mangrove forests and other tropical coastal species have been expanding northward and upslope since the last glacial maximum.[125,126,127,128,129]

In the coming decades and centuries, climate change will continue to transform many ecosystems throughout the Southeast,[6,130,131,132,133,134,135] which would affect many of the societal benefits these ecosystems provide. As a result, future generations can expect to experience, interact with, and potentially benefit from natural systems that are much different than those that we see today (Ch. 7: Ecosystems).[136,137]

Warming Winter Temperature Extremes

Changes in winter air temperature patterns are one aspect of climate change that will play an especially important role in the Southeast. By the late 21st century under the higher scenario (RCP8.5), the freeze-free season is expected to lengthen by more than a month. Winter air temperature extremes (for example, freezing and chilling events) constrain the northern limit of many tropical and subtropical species.[138,139,140,141,142,143,144] Certain ecosystems in the region are located near thresholds where small changes in winter air temperature regimes can trigger comparatively large and abrupt landscape-scale ecological changes (in other words, ecological regime shifts).[135,145] Reductions in the frequency and intensity of cold winter air temperature extremes can allow tropical and subtropical species to move northward and replace more temperate species. Where climatic thresholds are crossed, certain ecosystem and landscapes will be transformed by changing winter air temperatures.

Plant hardiness zone maps help convey the importance of winter air temperature extremes for species and natural systems in the Southeast. To help gardeners and farmers, the U.S. Department of Agriculture has produced plant hardiness zone maps that can be used to determine which species are most likely to survive and thrive in a given location. The plant hardiness zones are reflective of the frequency and intensity of winter air temperature

extremes in a specific region. Already, in response to climate change, plant hardiness zones in certain areas are moving northward and are expected to continue their northward and upslope progression.[139,142,146,147] Continued reductions in the frequency and intensity of winter air temperature extremes are expected to change which species are able to survive and thrive in a given location (Figure 19.15). For example, citrus species are sensitive to freezing and chilling temperatures.[148] However, in the future, climate change is expected to enable the survival of citrus in areas that are north of the current tolerance zone.[142]

The effects of changing winters reach far beyond just agricultural and garden plants. Along the coast, for example, warmer winter temperatures are expected to allow mangrove forests to move northward and replace salt marshes (Figures 19.16 and 19.17).[135,149,150,151,152]

Coastal wetlands, like mangrove forests and salt marshes, are abundant in the Southeast.[153,154] The societal benefits provided by coastal wetlands are numerous.[119] Hence, where coastal wetlands are abundant (for example, the Mississippi River Delta), their cumulative value can be worth billions of dollars each year and trillions of dollars over a 100-year period.[155] Coastal wetlands provide seafood, improve water quality, provide recreational opportunities, reduce erosion, support food webs, minimize flooding impacts, and support high rates of carbon sequestration.[118] Foundation species are species that create habitat and support entire ecological communities.[156,157] In coastal wetlands and many other ecosystems, foundation plant species play an especially important role. Hence, the loss and/or replacement of foundation plant species, like salt marsh grasses, will have ecological and societal consequences in certain areas.[135,145,157,158,159,160,161,162,163,164]

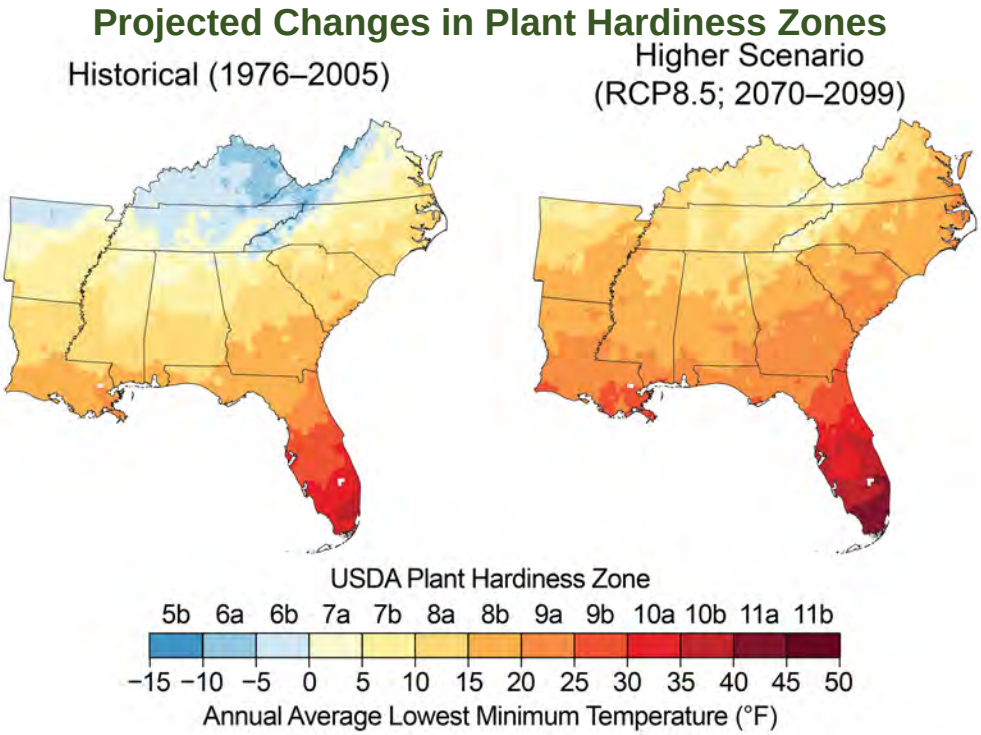


Figure 19.15: Increasing winter temperatures are expected to result in a northward shift of the zones conducive to growing various types of plants, known as plant hardiness zones. These maps show the mean projected changes in the plant hardiness zones, as defined by the U.S. Department of Agriculture (USDA), by the late 21st century (2070–2099) under a higher scenario (RCP8.5). The USDA plant hardiness zones are based on the average lowest minimum temperature for the year, divided into increments of 5°F. Based on these projected changes, freeze-sensitive plants, like oranges, papayas, and mangoes, would be able to survive in new areas.[142] Note that large changes are projected across the region, but especially in Kentucky, Tennessee, and northern Arkansas. Sources: NOAA NCEI and CICS-NC.

While salt marsh and mangrove wetlands both contain valuable foundation species, some of the habitat and societal benefits provided by existing salt marsh habitats will be affected by the northward expansion of mangrove forests.[145,158,160,161,164,165]

Salt Marsh Conversion to Mangrove Forest

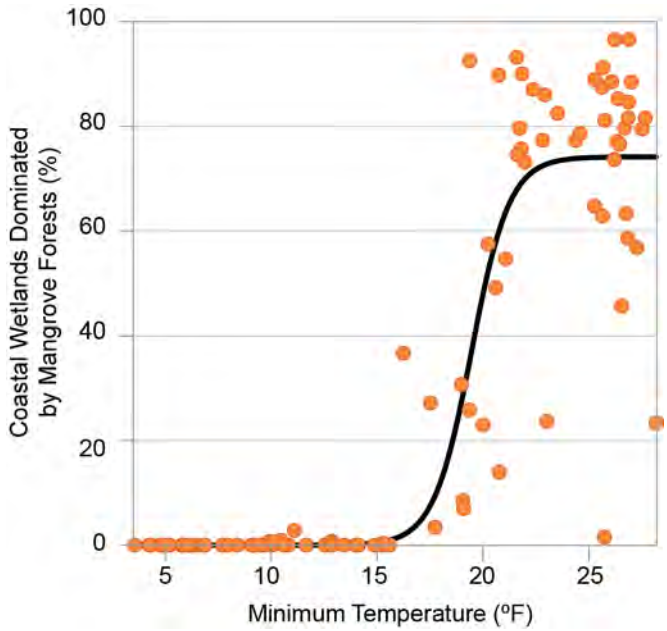


Figure 19.16: Where tropical and temperate ecosystems meet, warmer winter temperatures can lead to large ecological changes such as mangrove forest replacement of salt marshes along the Gulf and Atlantic Coasts. Mangrove forests are sensitive to freezing temperatures and are expected to expand northward at the expense of salt marshes. The figure shows the relationship between temperature and the percentage area dominated by mangrove forests. Mangrove expansion would entail a grassland-to-forest conversion, which would affect fish and wildlife habitat and many societal benefits. Source: adapted from Osland et al. 2013.[135] ©2012 Blackwell Publishing Ltd.

Transitioning Coastal Ecosystems

Figure 19.17: In Louisiana and parts of northern Florida, future coastal wetlands are expected to look and function more like the mangrove-dominated systems currently present in South Florida and the Caribbean. Like salt marshes (left), mangrove forests (right) provide coastal protection against wind and waves (Ch. 20: U.S. Caribbean, KM 2). Photo credit: Michael Osland.

In addition to plants, warmer winter air temperatures will also affect the movement and interactions between many different kinds of organisms. For example, certain insect species, including mosquitoes and tree-damaging beetles, are expected to move northward in response to climate change, which could affect human health and timber supplies.[30,144,166,167,168,169,170,171,172] And some bird species, including certain ducks, are not expected to migrate as far south in response to milder winters,[173] which could affect birding and hunting recreational opportunities. Many recreational fishery populations in tropical coastal areas are freeze-sensitive[138,174,175,176,177,178] and are, therefore, expected to move northward in response to warmer water and air temperatures. Although the appearance of tropical recreational fish, like snook for example, may be favorable for some anglers, the movement of tropical marine species is expected to greatly modify existing food webs and ecosystems (Ch. 7: Ecosystems, Figure 7.4).[179] Some problematic invasive species are expected to be favored by changing winters. For example, in South Florida, the Burmese python and the Brazilian pepper tree are two freeze-sensitive, nonnative species that have, respectively, decimated mammal populations and transformed native plant communities within Everglades National Park.[180,181,182,183,184,185,186,187,188] In the future, warmer winter temperatures are expected to facilitate the northward movement of these problematic invasive species, which would transform natural systems north of their current distribution.

Warm Winters Favor Invasive Species

Figure 19.18: Burmese pythons are apex predators (not preyed upon by other animals) that are sensitive to cold temperatures and are expected to be favored by warming winters. This photo is from Everglades National Park, where unintentionally introduced pythons have expanded and reduced native mammal populations. Photo credit: U.S. Geological Survey.

Changing Patterns of Fire

In the Southeast region, changing fire regimes (defined by factors including frequency, intensity, size, pattern, season, and severity) are expected to have a large impact on natural systems. Fire has historically played an important role in the region, and ecological diversity in many southeastern natural systems is dependent upon fire.[115,116,134,189] Although the total area burned by wildfire is greatest in the western United States, the Southeast has the largest area burned by prescribed fire (see Case Study "Prescribed Fire") and the highest number of wildfires.[134,190] In the future, rising temperatures and increases in the duration and intensity of drought are expected to increase wildfire occurrence and also reduce the effectiveness of prescribed fire.[3,4,5,6] Moreover, rapid urban expansion near managed forests has the potential to reduce opportunities to use prescribed fire, which could lead to native species declines, increased wildfire occurrence, and economic and health impacts.[134,191]

A recent example of the importance of fire lies in the forests of the southern Appalachians. Over the last century, invasive insects, logging, and pathogens have transformed forests in the region.[192] Warmer temperatures and insects have led to the loss of cold-adapted boreal communities, and flammable, fire-adapted tree species have been replaced by less flammable, fire-sensitive species—a process known as mesophication.[193,194] However, intense fires, like those observed in 2016, can halt the mesophication process. High temperatures, increases in accumulated plant material on the forest floor, and a four-month seasonal drought in the fall of 2016 collectively produced the worst wildfires the region has seen in a century. Intra-annual droughts, like the one in 2016, are expected to become more frequent in the future.[6] Thus, drought and greater fire activity[134] are expected to continue to transform forest ecosystems in the region (see Ch. 6: Forests, KM 1).

Case Study: Prescribed Fire

With wildfire projected to increase in the Southeast,[6,191] prescribed fire (the purposeful ignition of low-intensity fires in a controlled setting), remains the most effective tool for reducing wildfire risk.[4,195] Department of Defense (DoD) lands represent the largest reservoirs of biodiversity and native ecosystems in the region.[117] Military activities are a frequent source of wildfires, but increases in prescribed fire acres (Figure 19.19) show a corresponding decrease in wildfire ignitions for DoD.[4] Climate resilience by DoD is further achieved through restoration of native longleaf pine forests that occupy a wide range of site types, including wetland and well-drained soils—the latter leading many to characterize this forest as being drought resistant.[196,197,198,199] In addition to proactive adaptation through prescribed fire, DoD has been a leader in climate strategies that include regional conservation planning, ecosystem management, endangered species recovery, and research funding.

Wildlife and Prescribed Fire

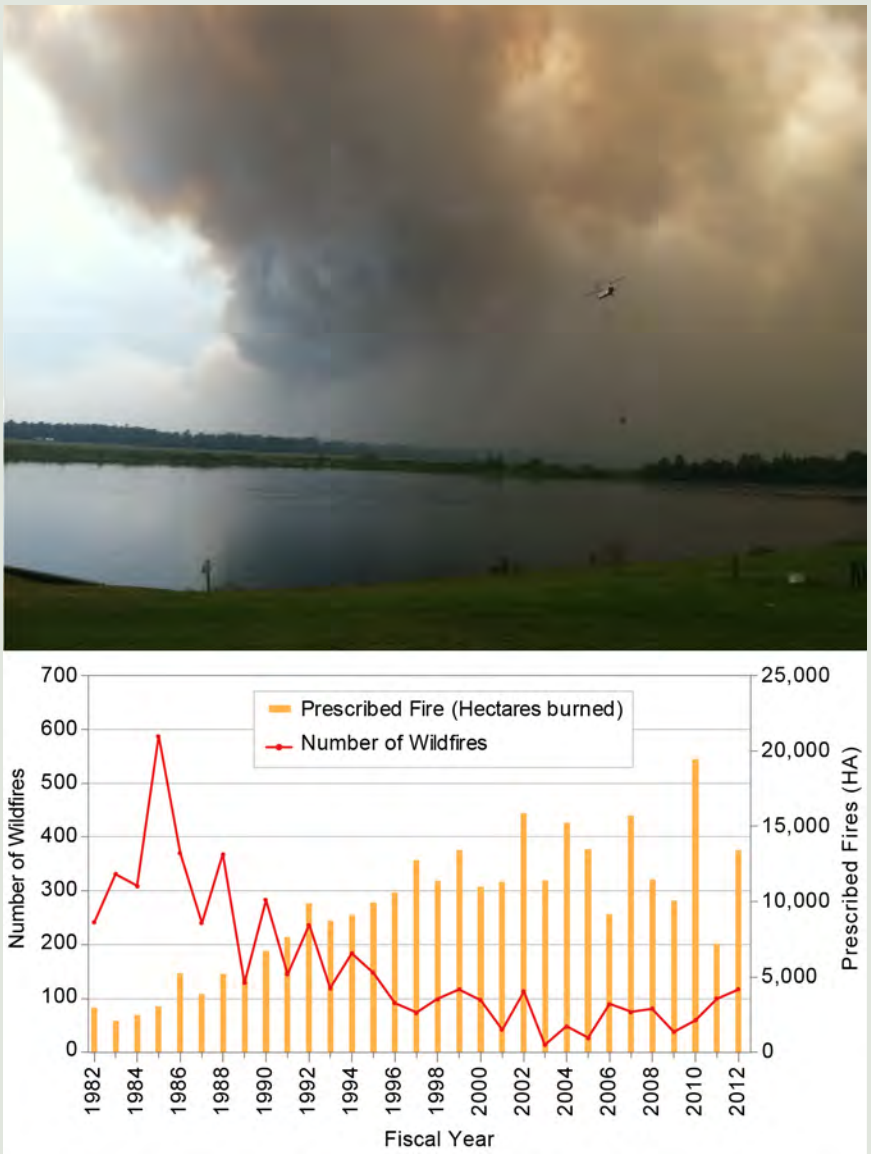


Figure 19.19: (top) A helicopter drops water on a 1,500-hectare wildfire on Hurlburt Field (Eglin Air Force Base) in Florida in June of 2012. (bottom) The increased use of prescribed fire at Ft. Benning, Georgia, led to a decrease in wildfire occurrence from 1982 to 2012. Photo credit: Kevin Hiers, Tall Timbers. Figure source: adapted from Addington et al. 2015.[4] Reprinted by permission of CSIRO Australia, ©CSIRO.

Rising Sea Levels and Hurricanes

Rising sea levels and potential changes in hurricane intensity are aspects of climate change that are expected to have a tremendous effect on coastal ecosystems in the Southeast (Ch. 8: Coastal, KM 2; Ch. 9: Oceans, KM 1). Since coastal terrestrial and freshwater ecosystems are highly sensitive to increases in inundation and salinity, sea level rise will result in the rapid conversion of these systems to tidal saline habitats. Historically, coastal ecosystems in the region have adjusted to sea level rise by vertical and horizontal movement across the landscape.[125,129,200,201] As sea levels rise in the future, some coastal ecosystems will be submerged and converted to open water, and saltwater intrusion will allow salt-tolerant coastal ecosystems to move inland at the expense of upslope and upriver ecosystems.[128,202,203,204,205,206,207,208] Where barriers are present (for example, levees and other coastal infrastructure), the potential for landward migration of natural systems will be reduced and certain coastal habitats will be lost (Ch. 20: U.S. Caribbean, KM 3).[204] With higher sea levels and increasing saltwater intrusion, the high winds, high precipitation rates, storm surges, and salts that accompany hurricanes will have large ecological impacts to terrestrial and freshwater ecosystems.[209,210]

An example of the effects of rising sea levels can be found in Louisiana, which faces some of the highest land loss rates in the world. The ecosystems of the Mississippi River Delta provide at least $12–$47 billion (in 2017 dollars) in benefits to people each year.[155] These benefits include hurricane storm protection, water supply, furs, habitat, climate stability, and waste treatment. However, between 1932 and 2016, Louisiana lost 2,006 square miles of land area (see Case Study "A Lesson Learned for Community Resettlement"),[211] due in part to high rates of relative sea level rise.[212,213,214,215] The rate of wetland loss during this period equates to Louisiana losing an area the size of one football field every 34 to 100 minutes.[211] To protect and restore the Louisiana coast, the Louisiana Coastal Protection and Restoration Authority (CPRA) has worked with local, state, and federal partners to iteratively develop a 2017 Coastal Master Plan that identifies investments that can provide direct restoration and risk reduction benefits.[216] The aim of the 50-year, $50-billion strategy is to sustain Louisiana's coastal ecosystems, safeguard coastal populations, and protect vital economic and cultural resources.[216]

Drought and Extreme Rainfall

Climate change is expected to intensify the hydrologic cycle and increase the frequency and severity of extreme events like drought and heavy rainfall. Drought and extreme heat can result in tree mortality and transform the region's forested ecosystems (Ch. 6: Forests, KM 1).[217,218,219,220,221,222,223] Drought can also affect aquatic and wetland ecosystems,[224] for example by contributing to mortality and ecological transformations in salt marshes,[225,226] mangrove forests,[227,228,229,230,231] and tidal freshwater forests.[232] In addition to drought, extreme rainfall events are also expected to become more frequent and severe in the future. The prolonged inundation and lack of oxygen that results from extreme rainfall can also result in mortality, such as the dieback of critical foundation plant species, and other large impacts to natural systems.[233] In combination, future increases in the frequency and severity of both extreme drought and extreme rainfall are expected to transform many ecosystems in the Southeast region. Natural systems in the region will have to become resistant and resilient to both too little water and too much water. The ecological transformations induced by these extreme events will affect many of the benefits that natural systems provide to society.

Warming Ocean Temperatures

Warming ocean temperatures due to climate change are expected to have a large effect on marine and coastal ecosystems (Ch. 9: Oceans, KM 3).[234,235,236] Many species are sensitive to small changes in ocean temperature; hence, the distribution and abundance of marine organisms are expected to be greatly altered by increasing ocean temperatures. For example, the distribution of tropical herbivorous fish has been expanding in response to warmer waters, which has resulted in the tropicalization of some temperate marine ecosystems and decreases in the cover of valuable macroalgal plant communities.[179] A decrease in the growth of sea turtles in the West Atlantic has been linked to higher ocean temperatures.[237] Due to climate change, warming ocean temperatures in the coming decades are expected to transform many marine and coastal ecosystems across the Southeast. However, the impacts to coral reef ecosystems in the region have been and are expected to be particularly dire. Coral reefs are biologically diverse ecosystems that provide many societal benefits, including coastal protection from waves, habitat for fish, and recreational and tourism opportunities.[238,239] However, coral reef mortality in the Florida Keys and across the globe has been very high in recent decades, due in part to warming ocean temperatures, nutrient enrichment, overfishing, and coastal development.[240,241,242,243,244] Small increases in ocean temperature can cause corals to expel the symbiotic algae upon which they depend for nourishment. When this happens, corals lose their color and die in a process known as coral bleaching (Ch. 9: Oceans, KM 1). Coral elevation and volume in the Florida Keys have been declining in recent decades,[245] and present-day temperatures in the region are already close to bleaching thresholds; hence, it is likely that many of the remaining coral reefs in the Southeast region will be lost in the coming decades.[246,247] In addition to warming temperatures, accelerated ocean acidification is also expected to contribute to coral reef mortality and decline.[248,249] When coral reefs are lost, coastal communities lose the many benefits provided by these valuable ecosystems, including lost tourism opportunities, a decline in fisheries, and a decrease in wave protection.[246,247]

Key Message 4

Economic and Health Risks for Rural Communities

Rural communities are integral to the Southeast's cultural heritage and to the strong agricultural and forest products industries across the region. More frequent extreme heat episodes and changing seasonal climates are projected to increase exposure-linked health impacts and economic vulnerabilities in the agricultural, timber, and manufacturing sectors. By the end of the century, over one-half billion labor hours could be lost from extreme heat-related impacts. Such changes would negatively impact the region's labor-intensive agricultural industry and compound existing social stresses in rural areas related to limited local community capabilities and associated with rural demography, occupations, earnings, literacy, and poverty incidence. Reduction of existing stresses can increase resilience.

In the Southeast, over 56% of land remains rural (nonmetropolitan) and home to approximately 16 million people, or about 17% percent of the region's population.[250] These rural areas are important to the social and economic well-being of the Southeast. Many in rural communities are maintaining connections to traditional livelihoods and relying on natural

resources that are inherently vulnerable to climate change. The Southeast has the second highest number of farmworkers hired per year compared to other National Climate Assessment (NCA) regions.[251] Climate trends and possible climate futures show patterns that are already impacting—and are expected to further impact—rural sectors, from agriculture and forestry to human health and labor productivity (Ch. 10: Ag & Rural, KM 3). For example, shrimping, oystering, and fishing along the coast are long-standing traditions in the coastal economy that are expected to face substantial challenges. For example, by the end of the century, annual oyster harvests in the Southeast are projected to decline between 20% (19%–22%) under a lower scenario (RCP4.5) and 46% (44%–48%) under a higher scenario (RCP8.5), leading to projected price increases of 48% (RCP4.5) to 140% (RCP8.5).[35] Projected warming ocean temperatures, sea level rise, and ocean and coastal acidification are raising concern over future harvests (Ch. 9: Oceans, KM 2).[35,252] While adaptation and resilience can moderate climate change impacts, rural areas generally face other stressors, such as poverty and limited access to healthcare, which will make coping to these climate-related challenges more difficult.

Heat-related stresses are presently a major concern in the Southeast. Future temperature increases are projected to pose challenges for human health. While recent regional temperature trends have not shown the same consistent rate of daytime maximum temperature increase as observed in other parts of the United States, climate model simulations strongly suggest that daytime maximum temperatures are likely to increase as humans continue to emit greenhouse gases into the atmosphere.[13] The resulting temperature increases are expected to add to the heat health burden in rural, as well as urban, areas.[35] Projected temperature increases also pose challenges for crop production dependent on periods of lower temperatures to reach full productivity. Drought has been a recurrent issue in the Southeast affecting agriculture, forestry, and water resources.[253] With rapid growth in population and overall demand, drought is increasingly a concern for water resource management sectors such as cities, ecosystems, and energy production.

Diverse Rural Regions

Urban and rural areas exist along a continuum from major metro areas to suburbs, small towns, and lightly populated places. These areas are linked through many processes, commuting patterns, and shared central services, such as airports and hospitals, that connect the risks. Rapid population growth with associated urbanization and suburbanization over the last several decades has resulted in a more fine-grained forest landscape with smaller and more numerous forest patches.[254] Agriculture, manufacturing, tourism, and other major economic sectors are spread across the Southeast region. Rural counties in the region generally have a diversified economy with a relatively low percentage being heavily dependent on one sector. While well known for agriculture and forestry, rural areas also support manufacturing and tourism.[250]

In 2013, approximately 34% of the U.S. manufacturing output, or about $700 billion (dollar year not reported), came from the Southeast and Texas, including rural areas.[255] While manufacturing growth has been particularly strong in the Southeast in recent years, future climate changes would pose challenges for economic competitiveness. For companies involved in food processing, there are additional secondary economic risks associated with climate impacts on crops and livestock that could alter price or availability.[64,255] Facilities that are energy- or water-intensive are more likely to face increases in the costs and

decreases in the availability of these resources, with potential impacts to their economic competitiveness.[246,255]

Energy production, and its dependence on water availability, is a key concern in the Southeast, given the region's growing population and large, diversified economy. An increasing number of high heat and dry days as the climate warms poses a risk to efficient power generation, particularly under conditions where the mode of primary generation moves towards natural gas and water-intensive nuclear power.[256]

Risks to Agriculture and Forestry

Agriculture, livestock rearing, and forestry activities are widespread and varied through the Southeast region.[7] Climate change is expected to have an overall negative impact on agricultural productivity in the United States,[35] although some crops could also become newly viable alternatives (Key Message 3, Figure 19.15). Increases in temperatures, water stress, freeze-free days, drought, and wildfire risks, together with changing conditions for invasive species and the movement of diseases, create a number of potential risks for existing agricultural systems (Ch. 10: Ag & Rural, KM 1).[7] In particular, precipitation trends for the Southeast region show an inclination towards slightly drier summers, which could reduce productivity, and wetter fall seasons, which can make it difficult to harvest the full crop. Multimodel averages of climate model simulations (CMIP3 [SRES A2] and CMIP5 [RCP8.5] higher scenarios) show that there is a greater risk of drier summers by the middle of the century in the western portion of the Southeast and in southern Florida, while wetter fall seasons are more likely in the eastern portion of the region.[257]

The conditions for raising and harvesting crops and livestock are projected to change. Higher temperatures can result in decreasing productivity of some cultivated crops, including cotton, corn, soybeans, and rice.[7] Livestock, which includes hogs and pigs, horses, ponies, mules, burros, and donkeys as well as poultry and processed poultry for consumption (for example, chicken nuggets), is a large component of the agricultural sector for these states and the Nation.[258] Livestock are all vulnerable to heat stress, and their care under projected future conditions would require new or enhanced adaptive strategies (Ch. 10: Ag & Rural, KM 3).

Recent changes in seasonal temperatures that are critical for plant development will continue to impact regionally important crops. Plants collected from the wild may become less available as the ideal conditions for their growth shift to other areas (see Case Study "Mountain Ramps"). Peaches—an important crop in the Southeast—require an adequate period of cool temperatures, called the chill period, to produce yields that are economically viable. Peaches also require warm temperatures at specific times during their development.[259] If the warm temperatures come too early, the chill periods could be too short or the peach blossoms can flower too soon and be in danger of late freeze impacts. A late freeze in March 2017 caused over a billion dollars of damages to peaches and other fruit crops.[84] To assist peach growers in adapting to such changes, researchers are working to develop peach varieties that can produce quality fruits in warmer winters and are developing winter chill models that can assist in adaptation planning efforts.[260,261]

Forests, both natural and plantation, in the Southeast are vulnerable to climate variability and change. Southeastern forests represent almost 27% of the U.S. total[262] and are the highest-valued crop in the region.[7] The vast majority of forest is held in private hands, primarily corporate. Forest cover ranges from almost 50% to 80% in these states, creating

large areas of interface between populations and forests.[262] Jobs in timber, logging, and support for agriculture and forestry totaled approximately 458,000.[263] (See Ch. 6: Forests, KM 3 for additional discussion on forest change impacts on rural landscapes.)

The Southeast is one of the most dynamic regions for forest change on the globe,[269] though much of the change owes to intensive rotations of pine production and economic forces that drive frequent conversion between forest and agricultural uses in rural areas.[270,271] Climate is expected to have an impact on the region's forests primarily through changes in moisture regimes.[272] Species migration westward across the eastern United States in response to changing precipitation patterns has already been noted.[273] Drought is likely to alter fire regimes and further interact with species distributions (see Key Message 3). The interactions of altered precipitation and natural disturbances will be important in understanding impacts to the forests not dominated by industrial forestry (Ch. 6: Forests, KM 1 and KM 3).[274]

Wildfire is a well-known risk in the Southeast region, where it occurs with greater frequency than any other U.S. region.[275] However, mitigation strategies, particularly the use of prescribed fire, can significantly reduce wildfire risk and have been widely adopted across rural communities in the Southeast.[190] A doubling of prescribed fire at the landscape scale has been found to reduce wildfire ignitions by a factor of four,[4] while it is well documented that prescribed fire reduces the potential for crown fire in treated forest stands.[276] With greater projected fire risks,[191,277] more attention on how to foster fire-adapted communities offers opportunities for risk reduction (see Case Study "Prescribed Fire" and Key Message 3).[278,279]

Case Study: Mountain Ramps

The Cherokee have been harvesting ramps, a wild onion (*Allium tricoccum*), in the southern Appalachians, their ancestral homelands, for thousands of years.[264,265] Collecting ramps for food sustenance is only one aspect of this cultural tradition. The family-bound harvesting techniques are equally as important and make up part of the deeply held tribal lifeways (Ch. 15: Tribes, KM 2). Ramps emerge in springtime and provide important nutrients after a long winter with a dearth of fresh vegetables. These plants grow in moist forest understory areas that are sensitive to temperature and soil moisture.[266]

Figure 19.20: This up-close image of a ramp (*Allium tricoccum*), harvested from the wild, shows leaves and the bulb/corm of the plant. Photo credit: Gary Kaufman, USDA Forest Service Southern Research Station.

In the southern Appalachians, ramps are threatened by two major processes: overharvesting pressures and a changing climate that could expose these plants to higher temperatures and lower soil moisture conditions during sensitive growth periods (Ch. 10: Ag & Rural, KM 1).[267,268] Although ramps are found all along the Appalachian mountain range, on Cherokee ancestral lands, they are already in their southernmost range. Climate change thus acts to increase the vulnerability of this plant to the existing stressors.

Heat, Health, and Livelihoods

Heat-related health threats are already a risk in outdoor jobs and activities. While heat illness is more often associated with urban settings, rural populations are also at risk. For example, higher rates of heat-related illness have been reported in rural North Carolina compared to urban locations.[280] However, strategies to reduce health impacts on hot days, such as staying indoors or altering times outdoors, are already contributing to reducing heat-related illness in the Southeast.[281]

Workers in the agriculture, forestry, hunting, and fishing sectors together with construction and support, waste, and remediation services work are the most highly vulnerable to heat-related deaths in the United States, representing almost 68% of heat-related deaths nationally.[282] Six of the ten states with the highest occupational heat-related deaths in these sectors are in the Southeast region, accounting for 28.6% of occupational heat-related deaths between 2000 and 2010.[282] By 2090, under a higher scenario (RCP8.5), the Southeast is projected to have the largest heat-related impacts on labor productivity in the country, resulting in average annual losses of 570 million labor hours, or $47 billion (in 2015 dollars, undiscounted), a cost representing a third of total national projected losses, although these figures do not include adaptations by workers or industries (Figure 19.21).[35]

Investing in increased cooling is one likely form of adaptation. Among U.S. regions, the Southeast is projected to experience the highest costs associated with meeting increased electricity demands in a warmer world.[35]

Compounding Stresses and Constraints to Adaptation

The people of the rural Southeast confront a number of social stresses likely to add to the challenges posed by increases in climate stresses.[283] Rural communities tend to be more vulnerable due to factors such as demography, occupations, earnings, literacy, poverty incidence, and community capacities (Ch. 10: Ag & Rural, KM 4).[8,9,10] Reducing stress associated with these factors can increase household and community resilience.[9,284]

Projected Changes in Hours Worked

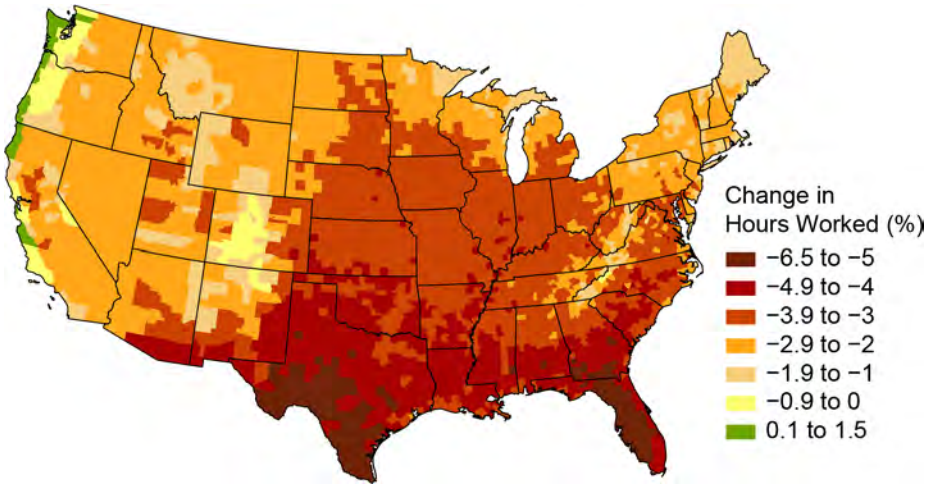


Figure 19.21: This map shows the estimated percent change in hours worked in 2090 under a higher scenario (RCP8.5). Projections indicate an annual average of 570 million labor hours lost per year in the Southeast by 2090 (with models ranging from 340 million to 820 million labor hours).[35] Estimates represent a change in hours worked as compared to a 2003–2007 average baseline for high-risk industries only. These industries are defined as agriculture, forestry, and fishing; hunting, mining, and construction; manufacturing, transportation, and utilities. Source: adapted from EPA 2017.[35]

Persistent rural poverty stands out in the Southeast (Figure 19.22). The rural counties in the region are experiencing higher levels of population loss (13% of rural counties lost population) and low educational attainment (38% of rural counties), with 35% of rural counties experiencing poverty rates of more than 20% persisting over approximately 30 years.[10] The Southeast is expected to experience the highest costs associated with meeting increased energy demands; an estimated $3.3 billion each year under a higher scenario (RCP8.5) and $1.2 billion annually under a lower scenario (RCP4.5) by the end of the century.[35] Energy poverty is a situation "where individuals or households are not able to adequately heat or provide other required energy services in their homes at affordable cost."[285] A case study from rural eastern North Carolina further explains energy poverty as a function of the energy efficiency of the home, energy provision infrastructure, physical health, low incomes, and support of social networks, which collectively influence households' choices about the amount of heating and cooling they can afford.[286] The National Weather Service (NWS) calculates degree days,[287] a way of tracking energy use. NWS starts with the assumption that when the average outside temperature is 65°F, heating or cooling is not needed in order to be comfortable. The difference between the average daily temperature and 65°F is the number of cooling or heating degrees for that day. These days can be added up over time—a month or a year—to give a combined estimate of energy needed for heating or cooling. Although heating costs are expected to decrease as the climate warms in the Southeast, the number of cooling degree days is expected to increase and the length of the cooling season expected to expand, increasing energy demand and exacerbating rural energy poverty (Figure 19.22).

The ability to cope with current and potential impacts, such as flooding, is further reduced by limited county resources. A study of hazard management plans (2004–2008) in 84 selected rural southeastern counties found these plans scored low across various criteria.[288] The rural, geographically remote locations contributed to more difficult logistics in reaching people. Interviewees also identified low-income and minority communities, substandard housing, lack of access to vehicles for evacuation, limited modes of communication, and limited local government capacity as contributing factors to difficulties in emergency planning.[288]

The healthcare system in the Southeast is already overburdened and may be further stressed by climate change. Between 2010 and 2016, more rural hospitals closed in the Southeast than any other region, with Alabama, Georgia, Mississippi, and Tennessee being among the top five states for hospital closures.[289] This strain, when combined with negative health impacts from climate change stressors (such as additional patient demand due to extreme heat and vector-borne diseases and greater flood risk from extreme precipitation events), increases the potential for disruptions of health services in the future. The Green River District Health Department recently did an assessment of ways to reduce vulnerability to negative health impacts of climate change in a mostly rural region of western Kentucky.[290] As a result, the local health department plans to enhance existing epidemiology, public health preparedness, and community health assessment services.[290]

Projected Changes in Cooling Degree Days

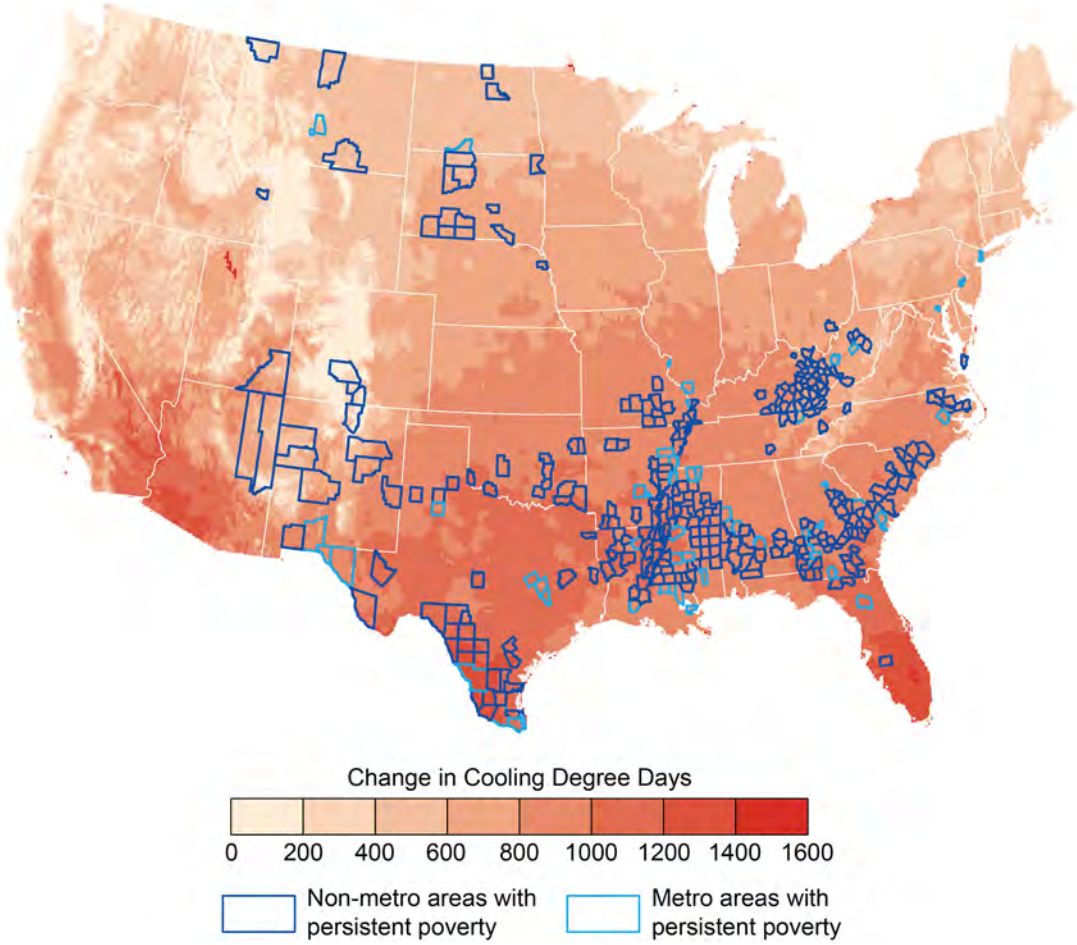


Figure 19.22: The map shows projected changes in cooling degree days by the mid-21st century (2036–2065) under the higher scenario (RCP8.5) based on model simulations. Rural counties experiencing persistent poverty are concentrated in the Southeast, where the need for additional cooling is expected to increase at higher rates than other areas of the country by mid-century. Sources: NOAA NCEI, CICS-NC, and ERT, Inc.

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Opening Image Credit

Red mangrove: © Katja Schulz/Flickr (CC BY 2.0). Adaptation: cropped top and bottom to conform to the size needed for publication.

Traceable Accounts

Process Description

Prior to identifying critical issues for the Southeast assessment focuses for the Fourth National Climate Assessment (NCA4), the Chapter Lead (CL) contacted numerous professional colleagues representing various geographic areas (e.g., Florida, Louisiana, and South Carolina) for expert opinions on critical climate change related issues impacting the region, with a particular emphasis on emerging issues since the Third National Climate Assessment (NCA3) effort.[77] Following those interviews, the CL concluded that the most pressing climate change issues to focus on for the NCA4 effort were extreme events, flooding (both from rainfall and sea level rise), wildfire, health issues, ecosystems, and adaptation actions. Authors with specific expertise in each of these areas were sought, and a draft outline built around these issues was developed. Further refinement of these focal areas occurred in conjunction with the public Regional Engagement Workshop, held on the campus of North Carolina State University in March 2017 and in six satellite locations across the Southeast region. The participants agreed that the identified issues were important and suggested the inclusion of several other topics, including impacts on coastal and rural areas and people, forests, and agriculture. Based on the subsequent authors' meeting and input from NCA staff, the chapter outline and Key Messages were updated to reflect a risk-based framing in the context of a new set of Key Messages. The depth of discussion for any particular topic and Key Message is dependent on the availability of supporting literature and chapter length limitations.

Key Message 1

Urban Infrastructure and Health Risks

Many southeastern cities are particularly vulnerable to climate change compared to cities in other regions, with expected impacts to infrastructure and human health (*very likely, very high confidence*). The vibrancy and viability of these metropolitan areas, including the people and critical regional resources located in them, are increasingly at risk due to heat, flooding, and vector-borne disease brought about by a changing climate (*likely, high confidence*). Many of these urban areas are rapidly growing and offer opportunities to adopt effective adaptation efforts to prevent future negative impacts of climate change (*very likely, high confidence*).

Description of evidence base

Multiple studies have projected that urban areas, including those in the Southeast, will be adversely affected by climate change in a variety of ways. This includes impacts on infrastructure[41,42,43,291,292,293] and human health.[30,31,38,294] Increases in climate-related impacts have already been observed in some Southeast metropolitan areas (e.g., Habeeb et al. 2015, Tzung-May Fu et al. 2015[12,39]).

Southeastern cities may be more vulnerable than cities in other regions of the United States due to the climate being more conducive to some vector-borne diseases, the presence of multiple large coastal cities at low elevation that are vulnerable to flooding and storms, and a rapidly growing urban and coastal population.[22,295,296]

Many city and county governments, utilities, and other government and service organizations have already begun to plan and prepare for the impacts of climate change (e.g., Gregg et al. 2017; FTA 2013; City of Fayetteville 2017; City of Charleston 2015; City of New Orleans 2015; Tampa Bay Water 2014; EPA 2015; City of Atlanta 2015, 2017; Southeast Florida Regional Climate Change Compact 2017[44,45,46,50,91,246,297,298,299]). A wide variety of adaptation options are available, offering opportunities to improve the climate resilience, quality of life, and economy of urban areas.[77,300,301,302,303,304]

Major uncertainties

Population projections are inherently uncertain over long time periods, and shifts in immigration or migration rates and shifting demographics will influence urban vulnerabilities to climate change. The precise impacts on cities are difficult to project. The scope and scale of adaptation efforts, which are already underway, will affect future vulnerability and risk. Technological developments (such as a potential shift in transportation modes) will also affect the scope and location of risk within cities. Newly emerging pathogens could increase risk of disease in the future, while successful adaptations could reduce public health risk.

Description of confidence and likelihood

There is *very high confidence* that southeastern cities will *likely* be impacted by climate change, especially in the areas of infrastructure and human health.

Key Message 2

Increasing Flood Risks in Coastal and Low-Lying Regions

The Southeast's coastal plain and inland low-lying regions support a rapidly growing population, a tourism economy, critical industries, and important cultural resources that are highly vulnerable to climate change impacts (*very likely, very high confidence*). The combined effects of changing extreme rainfall events and sea level rise are already increasing flood frequencies, which impacts property values and infrastructure viability, particularly in coastal cities. Without significant adaptation measures, these regions are projected to experience daily high tide flooding by the end of the century (*likely, high confidence*).

Description of evidence base

Multiple lines of research have shown that global sea levels have increased in the past and are projected to continue to accelerate in the future due to increased global temperature and that higher local sea level rise rates in the Mid-Atlantic and Gulf Coasts have occurred.[51,52,53,54,55,56,57,59,61,62]

Annual occurrences of high tide flooding have increased, causing several Southeast coastal cities to experience all-time records of occurrences that are posing daily risks.[1,52,58,60,61,63,67,68]

There is scientific consensus that sea level rise will continue to cause increases in high tide flooding in the Southeast as well as impact the frequency and duration of extreme water level events, causing an increase in the vulnerability of coastal populations and property.[1,60,63,67,68]

In the future, coastal flooding is projected to become more serious, disruptive, and costly as the frequency, depth, and inland extent grow with time.[1,2,35,64,65,67,68]

Many analyses have determined that extreme rainfall events have increased in the Southeast, and under higher scenarios, the frequency and intensity of these events are projected to increase.[19,21,88]

Rainfall records have shown that since NCA3, many intense rainfall events (approaching 500-year events) have occurred in the Southeast, with some causing billions of dollars in damage and many deaths.[68,82,84]

The flood events in Baton Rouge, Louisiana, in 2016 and in South Carolina in 2015 provide real examples of how vulnerable inland and coastal communities are to extreme rainfall events.[81,85,86]

The socioeconomic impacts of climate change on the Southeast is a developing research field.[65,71]

Major uncertainties

The amount of confidence associated with the historical rate of global sea level rise is impacted by the sparsity of tide gauge records and historical proxies as well as different statistical approaches for estimating sea level change. The amount of unpredictability in future projected rates of sea level rise is likely caused by a range of future climate scenarios projections and rate of ice sheet mass changes. Flooding events are highly variable in both space and time. Detection and attribution of flood events are difficult due to multiple variables that cause flooding.

Description of confidence and likelihood

There is *high confidence* that flood risks will *very likely* increase in coastal and low-lying regions of the Southeast due to rising sea level and an increase in extreme rainfall events. There is *high confidence* that Southeast coastal cities are already experiencing record numbers of high tide flooding events, and without significant adaptation measures, it is *likely* they will be impacted by daily high tide flooding.

Key Message 3

Natural Ecosystems Will Be Transformed

The Southeast's diverse natural systems, which provide many benefits to society, will be transformed by climate change (*very likely, high confidence*). Changing winter temperature extremes, wildfire patterns, sea levels, hurricanes, floods, droughts, and warming ocean temperatures are expected to redistribute species and greatly modify ecosystems (*very likely, high confidence*). As a result, the ecological resources that people depend on for livelihood, protection, and well-being are increasingly at risk, and future generations can expect to experience and interact with natural systems that are much different than those that we see today (*very likely, high confidence*).

Description of evidence base

Winter temperature extremes, fire regimes, sea levels, hurricanes, rainfall extremes, drought extremes, and warming ocean temperatures greatly influence the distribution, abundance, and performance of species and ecosystems.

Winter air temperature extremes (for example, freezing and chilling events) constrain the northern limit of many tropical and subtropical species.[30,48,127,132,135,138,139,140,141,142,143,144,145,148,149,150,152,166,167,168,169,170,172,173,174,175,176,177,178] In the future, warmer winter temperatures are expected to facilitate the northward movement of cold-sensitive species, often at the expense of cold-tolerant species.[132,135,142,145,149,150,152,166,169,173,179] Certain ecosystems are located near thresholds where small changes in winter air temperature regimes can trigger comparatively large and abrupt landscape-scale ecological changes (i.e., ecological regime shifts).[135,145,152]

Changing fire regimes are expected to have a large impact on natural systems. Fire has historically played an important role in the region, and ecological diversity in many southeastern natural systems is dependent upon fire.[115,116,134,189] In the future, rising temperatures and increases in the duration and intensity of drought are expected to increase wildfire occurrence and also reduce the effectiveness of prescribed fire.[3,4,5,6]

Hurricanes and rising sea levels are aspects of climate change that will have a tremendous effect on coastal ecosystems in the Southeast. Historically, coastal ecosystems in the region have adjusted to sea level rise via vertical and/or horizontal movement across the landscape.[125,129,200,201] As sea levels rise in the future, some coastal ecosystems will be submerged and converted to open water, and some coastal ecosystems will move inland at the expense of upslope and upriver ecosystems.[203,204] Since coastal terrestrial and freshwater ecosystems are highly sensitive to increases in inundation and/or salinity, sea level rise will result in the comparatively rapid conversion of these systems to tidal saline habitats. In addition to sea level rise, climate change is expected to increase the impacts of hurricanes; the high winds, storm surges, inundation, and salts that accompany hurricanes will have large ecological impacts to terrestrial and freshwater ecosystems.[209,210]

Climate change is expected to intensify the hydrologic cycle and increase the frequency and severity of extreme events. Extreme drought events are expected to become more frequent and severe. Drought and extreme heat can result in tree mortality and transform southeastern forested ecosystems.[217,218,219,220,221,222,223] Drought can also affect aquatic and wetland ecosystems.[224,225,226,227,228,229,232] Extreme rainfall events are also expected to become more frequent and severe in the future. The prolonged inundation and lack of oxygen that result from extreme rainfall events can also result in mortality and large impacts to natural systems.[233] In combination, future increases in both extreme drought and extreme rainfall are expected to transform many southeastern ecosystems.

Warming ocean temperatures due to climate change are expected to have a large effect on marine and coastal ecosystems.[234,235,236] Many species are sensitive to small changes in ocean temperature; hence, the distribution and abundance of marine organisms are expected to be greatly altered by increasing ocean temperatures. For example, the distribution of tropical herbivorous fish has been expanding in response to warmer waters, which has resulted in the tropicalization of some temperate marine ecosystems and decreases in the cover of valuable macroalgal plant communities.[179] A decrease in the growth of sea turtles in the West Atlantic has been linked to higher ocean temperatures.[237] The impacts to coral reef ecosystems have been and are expected to be particularly dire. Coral reef mortality in the Florida Keys and across the globe has been very high in recent decades, due in part to warming ocean temperatures, nutrient enrichment, overfishing, and coastal development.[240,241,242,243,244] Coral elevation and volume in the Florida Keys have been

declining in recent decades,[245] and present-day temperatures in the region are already close to bleaching thresholds; hence, it is likely that many of the remaining coral reefs in the Southeast will be lost in the coming decades.[246,247] In addition to warming temperatures, accelerated ocean acidification is also expected to contribute to coral reef mortality and decline.[248,249]

Major uncertainties

In the Southeast, winter temperature extremes, fire regimes, sea level fluctuations, hurricanes, extreme rainfall, and extreme drought all play critical roles and greatly influence the distribution, structure, and function of species and ecosystems. Changing climatic conditions (particularly, changes in the frequency and severity of climate extremes) are, however, difficult to replicate via experimental manipulations; hence, ecological responses to future climate regimes have not been fully quantified for all species and ecosystems. Natural ecosystems are complex and governed by many interacting biotic and abiotic processes. Although it is possible to make general predictions of climate change effects, specific future ecological transformations can be difficult to predict, especially given the number of interacting and changing biotic and abiotic factors in any specific location. Uncertainties in the range of potential future changes in multiple and concurrent facets of climate and land-use change also affect our ability to predict changes to natural systems.

Description of confidence and likelihood

There is *high confidence* that climate change (e.g., changing winter temperatures extremes, changing fire regimes, rising sea levels and hurricanes, warming ocean temperatures, and more extreme rainfall and drought) will *very likely* affect natural systems in the Southeast region. These climatic drivers play critical roles and greatly influence the distribution, structure, and functioning of ecosystems; hence, changes in these climatic drivers will transform ecosystems in the region and greatly alter the distribution and abundance of species.

Key Message 4

Economic and Health Risks for Rural Communities

Rural communities are integral to the Southeast's cultural heritage and to the strong agricultural and forest products industries across the region. More frequent extreme heat episodes and changing seasonal climates are projected to increase exposure-linked health impacts and economic vulnerabilities in the agricultural, timber, and manufacturing sectors (*very likely, high confidence*). By the end of the century, over one-half billion labor hours could be lost from extreme heat-related impacts (*likely, medium confidence*). Such changes would negatively impact the region's labor-intensive agricultural industry and compound existing social stresses in rural areas related to limited local community capabilities and associated with rural demography, occupations, earnings, literacy, and poverty incidence (*very likely, high confidence*). Reduction of existing stresses can increase resilience (*very likely, high confidence*).

Description of evidence base

Analysis of the sensitivity of some manufacturing sectors to climate changes anticipates secondary risks associated with crop and livestock productivity.[64,255]

Multiple analyses anticipate that energy- or water-intensive industries could face water stress and increased energy costs.[8,64,255,256]

A large body of evidence addresses the sensitivity of many crops grown in the Southeast to changing climate conditions including increased temperatures, decreased summer rainfall, drought, and change in the timing and duration of chill periods.[7,35] Extensive research documents livestock sensitivity to heat stress.[7]

Multiple lines of evidence indicate that forests are likely to be impacted by changing climate, particularly moisture regimes and potential changes in wildfire activity.[191,195,272,274] There is extensive research on heat-related illness and mortality among those living and working in the Southeast. While there is more evidence focused on urban areas, limited research has identified higher levels of heat-related illness in rural areas.[280,281] Research on occupational heat-related mortality identifies some of the Nation's highest levels in southeastern states.[282] Computer model simulations of heat-related reductions in labor productivity anticipate the greatest losses will occur in the Southeast. However, these models do not account for adaptations that may reduce estimated losses.[35,64] By the end of the century, mean annual electricity costs are estimated at $3.3 billion each year under RCP8.5 (model range: $2.4 to $4.2 billion; in 2015 dollars, undiscounted) and mean $1.2 billion each year under RCP4.5 (model range $0.9 to $1.9 billion; in 2015 dollars, undiscounted).[35]

Rural communities tend to be vulnerable due to factors such as demography, occupations, earnings, literacy, and poverty incidence.[8,9,10,250,283,284,305] Reducing the stress created by such factors can improve resilience.[9,284] The availability and accessibility of planning and health services to support coping with climate-related stresses are limited in the rural Southeast.[288,289]

Major uncertainties

There are limited studies documenting direct connections between climate changes and economic impacts. Models are limited in their ability to incorporate adaptation that may reduce losses. These factors restrict the potential to strongly associate declines in agricultural and forest productivity with the level of potential economic impact.

Projections of potential change in the frequency and extent of wildfires depend in part on models of future population growth and human behavior, which are limited, adding to the uncertainty associated with climate and forest modeling.

Many indicators of vulnerability are dynamic, so that adaptation and other changes can affect the patterns of vulnerability to heat and other climate stressors over time. Limited studies indicate concerns over the planning and preparedness of capacity at local levels; however, information is limited.

Projected labor hours lost vary by global climate model, time frame, and scenario, with a mean of 0.57 and a model range of 0.34–0.82 billion labor hours lost each year for RCP8.5 by 2090. The annual mean projected losses are roughly halved (0.28 billion labor hours) and with a model range from 0.19 to 0.43 billion labor hours lost under RCP4.5 by 2090.[35]

Description of confidence and likelihood

There is *high confidence* that climate change (e.g., rising temperatures, changing fire regimes, rising sea levels, and more extreme rainfall and drought) will *very likely* affect agricultural and forest products industries, potentially resulting in economic impacts. There is *high confidence* that increases in temperature are *very likely* to increase heat-related illness, deaths, and loss of labor productivity without greater adaptation efforts.

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Attachment 2

Missed Opportunities for Efficiency in Virginia

Prepared for Consumers Union

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Applied Economics Clinic
Economic and Policy Analysis of Energy, Environment and Equity

Executive Summary

Dominion Energy Virginia (DEV or Dominion) is asking state utility regulators to approve billions of dollars in new spending to increase nuclear and natural gas capacity over the next 10 years in order meet its forecast for future energy demand. These costs would be passed on to consumers in the form of substantially higher utility bills. While Dominion has invested in energy efficiency—a cost-effective method to lower energy demand and reduce customer bills—it has done so at much lower levels than utilities in other states. In a recent study by the American Council for an Energy-Efficient Economy (ACEEE), Virginia ranked twenty-ninth among states for energy efficiency, suggesting substantial room for expanding energy efficiency efforts within the state. Lower demand also reduces the need for new power plants. Because new power plants are expensive and the cost of building them is borne by ratepayers, fewer new power plants means consumers could save even more. This report investigates the impact of various levels of energy efficiency on electric rates and bills of Dominion customers. We find that by investing in energy efficiency, Dominion customers would enjoy lower rates and bills while future energy demand would be met with fewer than half of the new power plants currently proposed by Dominion.

Dominion customer bills would decrease with greater energy efficiency savings, a missed opportunity compared to Dominion's current plans.

As compared to Dominion's planned energy efficiency ("Very Low Efficiency" in Table ES-1 below), more ambitious energy efficiency scenarios ("Low Efficiency" and "Medium Efficiency") reduce the average Dominion residential customer's annual electric bill by $41 to $92 in 2028. When Dominion residential customers' annual energy efficiency savings in 2028 are added together, savings total $102 to $229 million. Cumulatively, from 2018 through 2028, customer bill savings total $800 million to $1.7 billion.

Table ES-1. Average Virginia DEV residential electric bills

	Very Low Efficiency	Low Efficiency	Medium Efficiency
2028 Total Bills for all Residential Customers	$3,987 million	$3,885 million	$3,758 million
2028 Annual Bill for Average Residential Customer	$1,603	$1,562	$1,511

Bill savings from more energy efficiency outweigh the costs associated with them.

Utility costs—like those of building new capacity infrastructure, generation, transmission and distribution, or energy efficiency programs and their administration—are passed on to customers through their electric rates. The cost-benefit balance in the Low and Medium Efficiency scenarios is tipped in favor of increasing energy efficiency primarily through avoided capacity costs, as increasing energy efficiency lowers the need for new capacity additions. When combined with avoided transmission and distribution costs, the bill savings for residential customers outweigh the costs associated with energy efficiency programs.

Fewer power plants would be needed due to lower demand resulting from greater energy efficiency.

We created three energy efficiency scenarios to examine the impact of savings outlined by DEV in their Integrated Resource Plan (IRP), as well as two scenarios that explore energy efficiency levels above and beyond the current trajectory outlined by DEV. As shown below, greater energy efficiency reduces future electricity demand and reduces the need for additional capacity. In the Medium Efficiency scenario, enough energy is saved to eliminate the need for 2.4 GWs of new power plants. While this report assumes that new natural gas plants will serve marginal capacity (based on Dominion's IRP), it should be noted that new nuclear capacity would incur even higher costs.

Table ES-2. Very Low Efficiency, Low Efficiency, and Medium Efficiency scenarios

Scenario	Very Low Efficiency (VLE)	Low Efficiency (LE)	Medium Efficiency (ME)
Customer bills?	Most expensive	Second least expensive	Least expensive
Complies with 7.2 TWh EERS goal in what year?	2022	2020	2020
Complies with Virginia Renewable Portfolio Standard (RPS)?	Yes	Yes	Yes
New 1.0 GW natural gas power plants called for in 2028?	4.0	3.5	1.7

The differences in cost between higher energy efficiency scenarios and business-as-usual represent a missed benefit in terms of annual costs and changes to customer rates. If Dominion stays on its current path based on its IRP, in 2028, its residential customers will pay $102 million more on electricity than they would with Low Efficiency savings and $229 million more than with Medium Efficiency savings. It would benefit ratepayers, therefore, for DEV to increase energy efficiency to greater levels.

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I. Introduction

In 2007, the Virginia legislature passed SB 1416, which set a total state-wide energy efficiency goal 10.7 million megawatt-hours (MWh) annual savings by 2022.[1] SB 1416 noted that "it is in the public interest…to promote cost-effective conservation of energy through fair and effective demand side management, conservation, energy efficiency, and load management programs."[2] SB 1416 directs the State Corporation Commission (SCC) to evaluate whether the 10.7 million MWh goal by 2022 could be met cost-effectively; the Commission confirmed that it could in a 2008 report.[3] In 2015, Virginia Governor Terry McAuliffe accelerated the timeline of achieving the efficiency goal by two years, from 2022 to 2020, and formed an Executive Committee on Energy Efficiency to develop strategies to meet the goal. Together, SB 1416, the SCC report, and the Governor's Executive Committee on Energy Efficiency, form the basis of Virginia's energy efficiency resource standard (EERS)—a non-mandatory regulatory policy.

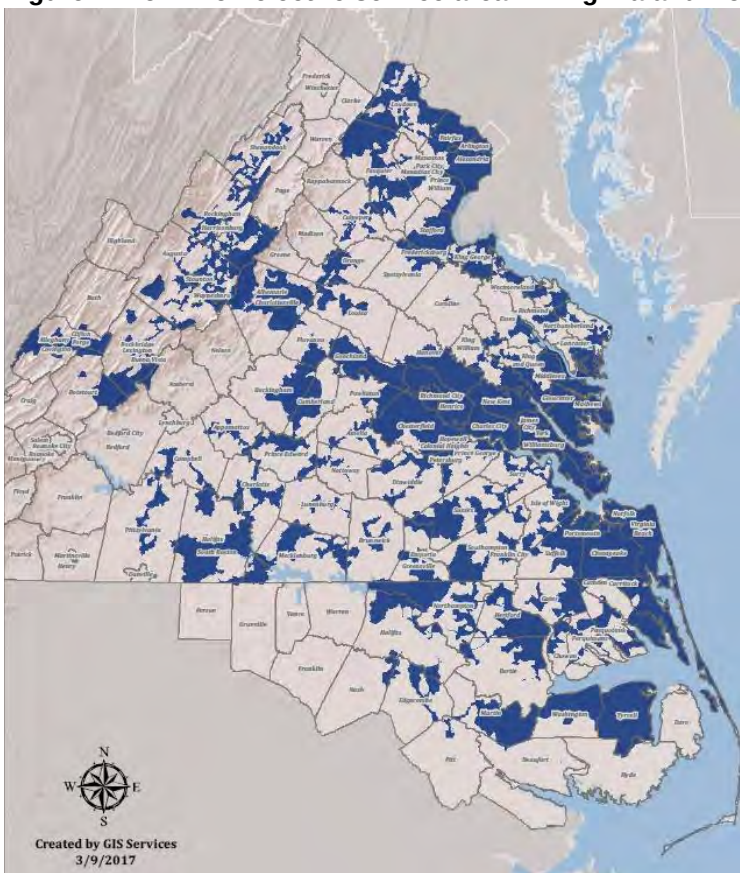
In April 2017, Virginia's 'Energy Efficiency Roadmap: Policy and Program Recommendations' was released.[4] The roadmap forecasts that Virginia will achieve just 36 percent of its annual 10.7 million MWh energy efficiency goal if actions are limited to projected policies and programs, leaving a statewide efficiency savings deficit of 6.9 million MWh annual savings in 2020. The Roadmap promotes steadily increasing energy savings targets on a long-term basis, beginning in 2018, to achieve wider-reaching energy efficiency programs in the residential and commercial sectors that achieve greater electricity savings.

In this report, the Applied Economics Clinic (AEC) investigates the impact of various levels of energy efficiency savings on electric rates of customers of the Dominion Energy subsidiary, Virginia Electric and Power Company (VEPCO), d/b/a Dominion Energy Virginia (DEV), in its Virginia service territory only (excluding their North Carolina territory, see Figure 1 below for reference). For clarity, we refer to the company as Dominion Energy Virginia (DEV) throughout the report. Virginia sales represented 95 percent of total DEV sales in 2016, with sales to North Carolina making up the remaining 5 percent. In 2016, DEV provided 68 percent of the

[1] SB 1416 calls for 10 percent cumulative annual efficiency savings (savings including past years and current year measures) relative to 2006 electric sales; Virginia Acts of Assembly, SB 1416, Chapter 933, April 4, 2007, http://leg1.state.va.us/cgi-bin/legp504.exe?071+ful+CHAP0933.
[2] Virginia Acts of Assembly, SB 1416, Chapter 933, April 4, 2007, http://leg1.state.va.us/cgi-bin/legp504.exe?071+ful+CHAP0933.
[3] Commonwealth of Virginia, State Corporation Commission, Report to the Commission on Electric Utility Regulation of the Virginia General Assembly and the Governor of the Commonwealth of Virginia, Case No. PUE-2007-00049, September 1, 2008, https://www.scc.virginia.gov/comm/reports/2008_ceur.pdf.
[4] Governor's Executive Committee, Virginia Energy Efficiency Roadmap: Policy and Program Recommendations, April 6, 2017, https://www.dmme.virginia.gov/de/LinkDocuments/GEC/4%20-%20Virginia%20Energy%20Efficiency%20Roadmap.pdf.

Commonwealth's electric sales across all sectors, and therefore, their share of the state's energy efficiency goal is 7.2 million MWh annual savings.[5]

Figure 1. Dominion electric service area in Virginia and North Carolina (in dark blue)



Source: *Reproduced from Dominion Energy. 2017. https://www.dominionenergy.com/library/domcom/pdfs/virginia-power/service-territory.pdf.*

We examined the impact of energy efficiency savings on customer electric rates under three scenarios:

- **Very Low Efficiency:** The Very Low Efficiency (VLE) scenario uses the planned (approved and proposed) energy efficiency savings presented in DEV's 2017 Integrated Resource Plan (IRP), as well as DEV's own forecast of peak and annual energy, and reaches its share of voluntary policy-prescribed annual efficiency savings, equal to 7.2

[5] Energy Information Administration (EIA) 861 2016.

million MWh, in 2022.[6]

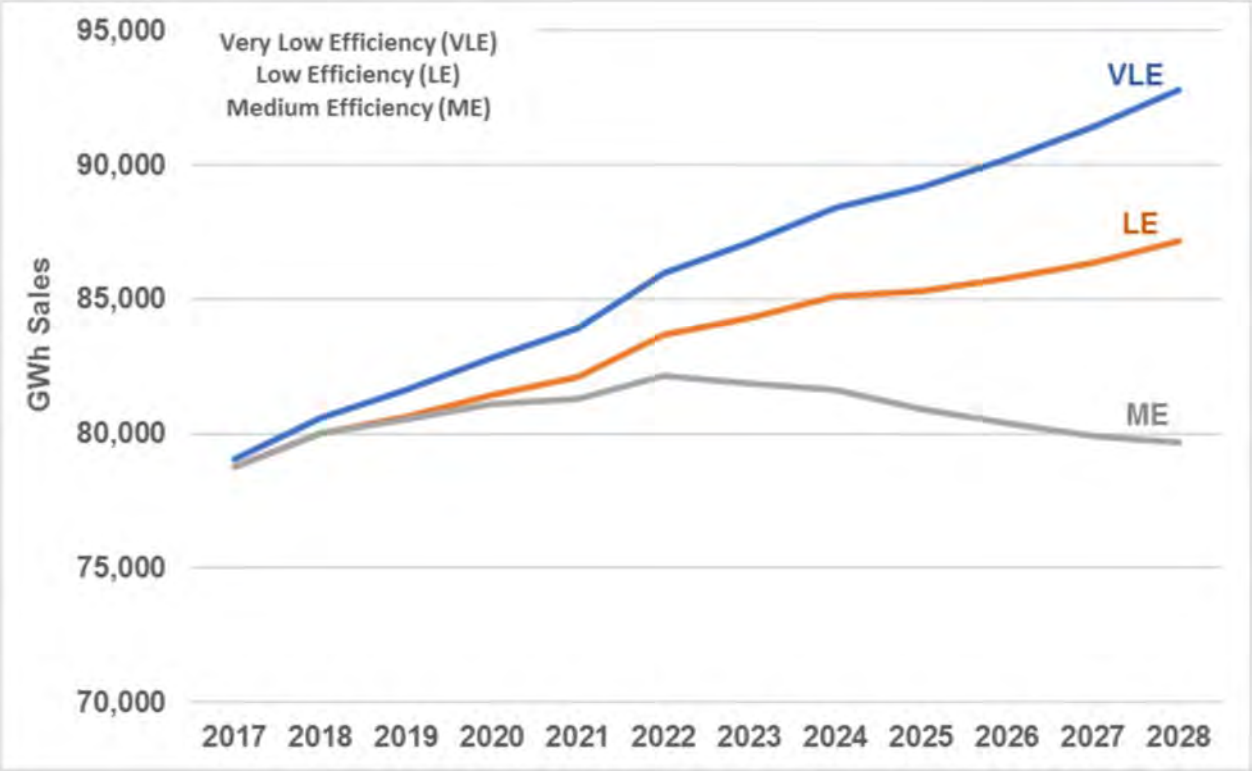
- **Low Efficiency:** The Low Efficiency (LE) scenario increases DEV's efficiency investments to achieve the 7.2 million MWh annual cumulative savings goal by 2020, after which point we assume that annual additions to energy efficiency savings (new measures) remain constant as a share of current year sales throughout the remainder of the period while total annual savings grow.

- **Medium Efficiency:** The Medium Efficiency (ME) scenario ramps up DEV's energy efficiency savings to match the U.S. utilities with the highest savings targets, using Eversource in Massachusetts as an example. We assume that DEV will reach 7.2 million MWh annual cumulative savings by 2020, after which point annual additions to energy efficiency savings (new measures) continue to rise until they reach 3 percent of sales in 2023 and then remain constant while total annual savings grow (see Figure 2 below for DEV's total sales in each of the three scenarios).

Baseline energy sales for all three scenarios come from the forecast in Dominion's 2017 IRP. Dominion's actual sales have not met DEV's projections in historical years, indicating overestimation in IRP forecasts.[7] Correcting for this overestimation in sales would lead to additional consumer savings through the avoidance of new generating capacity to meet forecasted demand (Figure 2).

[6] 7.2 million MWh savings equals 10 percent total annual efficiency savings relative to DEV 2006 sales. (10.7 million MWh is 10 percent of state-wide 2006 sales.) Annual total savings are typically called "cumulative" while savings from new measures (installed that year) are called annual incremental.
[7] Virginia Electric and Power Company's Report of its Integrated Resource Plan, Docket No. E-100, Sub 147, May 1, 2017, https://www.dominionenergy.com/library/domcom/pdfs/corporate/2017-irp.pdf.

Figure 2. Annual electricity sales in each DEV Virginia energy efficiency scenario

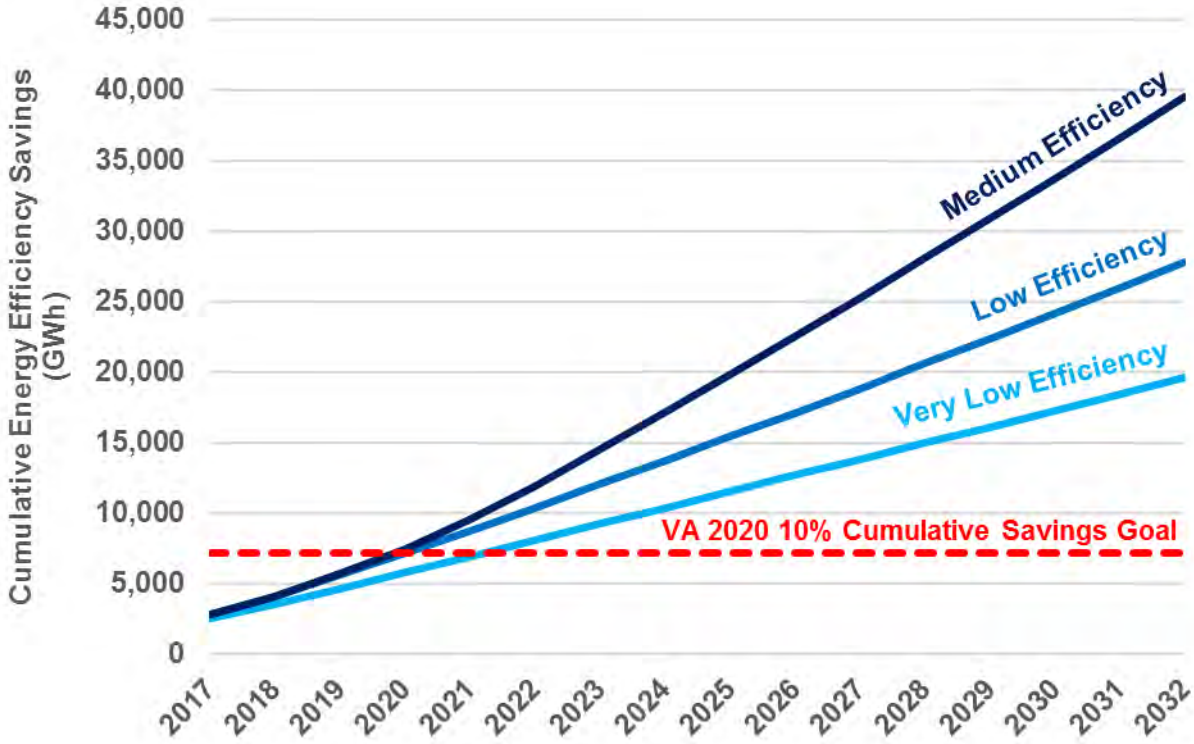


To examine the sensitivity of DEV's customer costs to variations in the level of energy efficiency savings (from IRP projected sales) we created a spreadsheet model of the three scenarios introduced above:

- **Very Low Efficiency:** 7.2 million MWh annual cumulative efficiency savings by 2022, achieving 1,197 GWh in total efficiency savings in 2028
- **Low Efficiency:** 7.2 million MWh annual cumulative efficiency savings by 2020 then slow growth in savings thereafter, achieving 1,813 GWh in total efficiency savings in 2028, and
- **Medium Efficiency:** 7.2 million MWh annual cumulative efficiency savings by 2020 then more ambitious growth in savings, achieving 2,840 GWh in total efficiency savings in 2028 (based on current efficiency savings rates of Eversource in Massachusetts).

The input assumptions for these scenarios differ only in the expected amount of energy efficiency (see Figure 3).

Figure 3. Annual cumulative energy savings in each DEV energy efficiency scenario



To balance sales with generation while maintaining DEV's obligation to be available to meet customers' needs during times of peak electric demand,[8] we adjust additions of new natural gas power plants in future years.[9] In Dominion's IRP, natural gas power plants are the new resource investments that are driven by consumer demand and marginal capacity needs; the other additions in the IRP are renewables that have a role in meeting Virginia's voluntary Renewable Energy Portfolio Goal.[10] However, it should be noted that new nuclear capacity would result in even higher costs and lower greenhouse gas emissions than those modeled in the scenarios.[11]

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[8] Dominion's coincident capacity reserve requirement of 12.5 percent.
[9] With the exception of the IRP scenario. We do not adjust future natural gas additions in the IRP scenario. This results in an excess capacity position in some years, as acknowledged in DEV's IRP report.
[10] For more details on Virginia's Voluntary Renewable Energy Portfolio Goal refer to Section III.
[11] The third nuclear reactor Dominion is planning to build in Virginia is estimated to cost in the range of $19 billion. See "US NRC approves new nuclear unit for Dominion's North Anna plant in Virginia," May 31, 2017, Platts S&P Global, accessed at https://www.platts.com/latest-news/electric-power/washington/us-nrc-

For simplicity, we assume that, for DEV's existing and planned generating units, each generation type's rate of operation (capacity factor) follows the Dominion IRP and that DEV will sell excess generation (or buy deficit generation) from the greater PJM region.[12] The only changes to capacity were made to natural gas additions in future years in the Low Efficiency and Medium Efficiency scenarios. While dispatch rates could change as energy efficiency increases, not only does assuming they remain stable allow us to single out the effects of energy efficiency, but DEV is free to—and has a financial incentive to—sell their excess generation within PJM. All three scenarios meet Virginia's renewable energy goal.[13] The methodology and input assumptions used in this report are described below in Section III.

Our analysis found the lowest residential bills with the greatest energy efficiency savings (the Medium Efficiency scenario) and the highest customer bills with the smallest savings (the Very Low Efficiency scenario). The difference in costs between these two scenarios represents a missed opportunity for DEV's customers.

The structure of this report is as follows: Section II presents our findings and Section III presents the methodology and assumptions utilized in our analysis.

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approves-new-nuclear-unit-for-dominions-21892141.

[12] The simple dispatch model created for this analysis was designed to capture DEV-owned plant operations only, to answer the question about the amount of future generating capacity in Virginia that could be avoided (and the cost savings to consumers) through additional energy efficiency in the state. DEV owns capacity sufficient to meet its peak demand in its own service territory plus its required reserve margin; however, DEV's generating units operate within the larger PJM region, and thus the dispatch of DEV's existing units is affected by supply and demand throughout all of PJM. PJM's 2018 forecast of anticipated demand predicted that electricity demand will continue to decline over the next several years and that peak summer demand in 2018 will require 1,843 fewer MWs of power than in 2017 (PJM Resource Adequacy Planning Department, PJM Load Forecast Report, January 2018, https://www.eenews.net/assets/2018/01/02/document_ew_02.pdf.). Increasing the amount of energy efficiency in Virginia can affect the dispatch of units outside of the state. Similarly, demand in other parts of the region could keep DEV's plants dispatching at historic levels even with increased energy efficiency in Virginia. This is the basis for the assumption in the report that the capacity factors for each unit type are held constant, and that DEV sells/buys excess/deficit generation into/from the market.

[13] For more details on Virginia's Voluntary Renewable Energy Portfolio Goal refer to Section III.

II. Findings

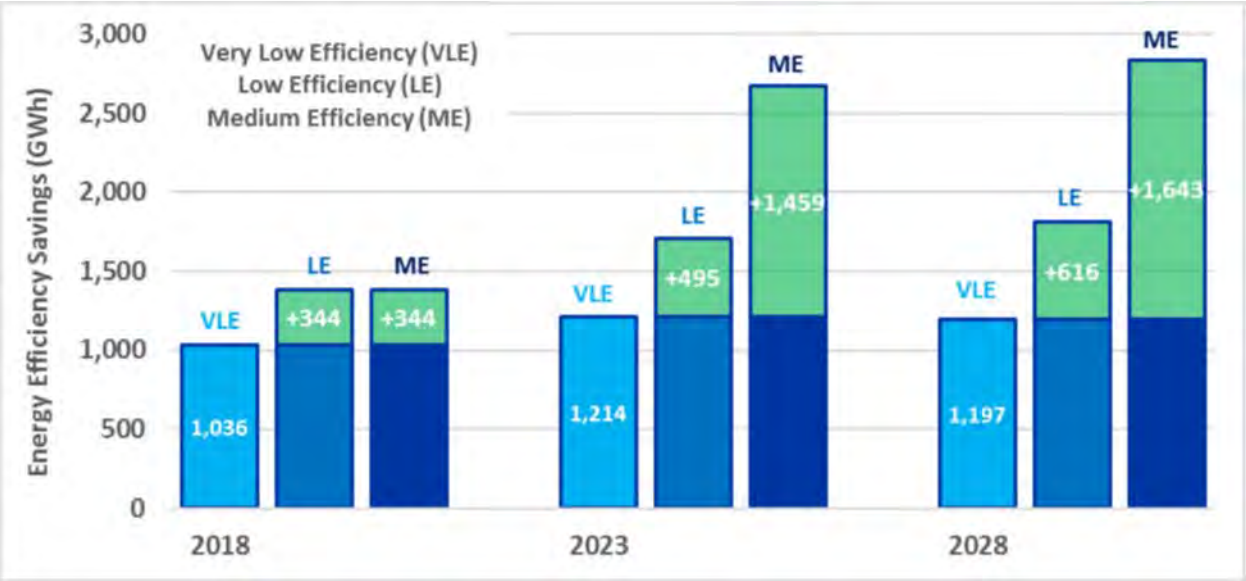
Energy efficiency savings reduce the need for investment in new generating capacity and the expense of generating electricity using fossil fuels like natural gas and coal. The result is lower costs for consumers and a reduction in greenhouse gas emissions and other pollutants.

Generation and Capacity

The figures that follow present results both in terms of their absolute amounts and the difference (called "delta") between the Very Low Efficiency (VLE) scenario and the Low Efficiency (LE) and Medium Efficiency (ME) scenarios.[14] This style of data presentation is standard practice in the energy analysis field and serves to focus our findings on changes that are expected to occur if efficiency savings are raised above the current trajectory identified in DEV's IRP. Additional savings are balanced by fewer new additions of natural gas power plants. Where this balancing process is imperfect or is constrained by DEV's obligation to ensure power is delivered at times of peak use, excess generation is assumed to be sold to other utilities.

Both the Low Efficiency scenario and Medium Efficiency scenario have more gigawatt-hour (GWh) energy efficiency savings than the Very Low Efficiency scenario (see Figure 4). Peak energy megawatt (MW) savings follow the pattern of annual energy savings in GWh (see Figure 5).

Figure 4. Virginia DEV net energy efficiency savings (GWh)

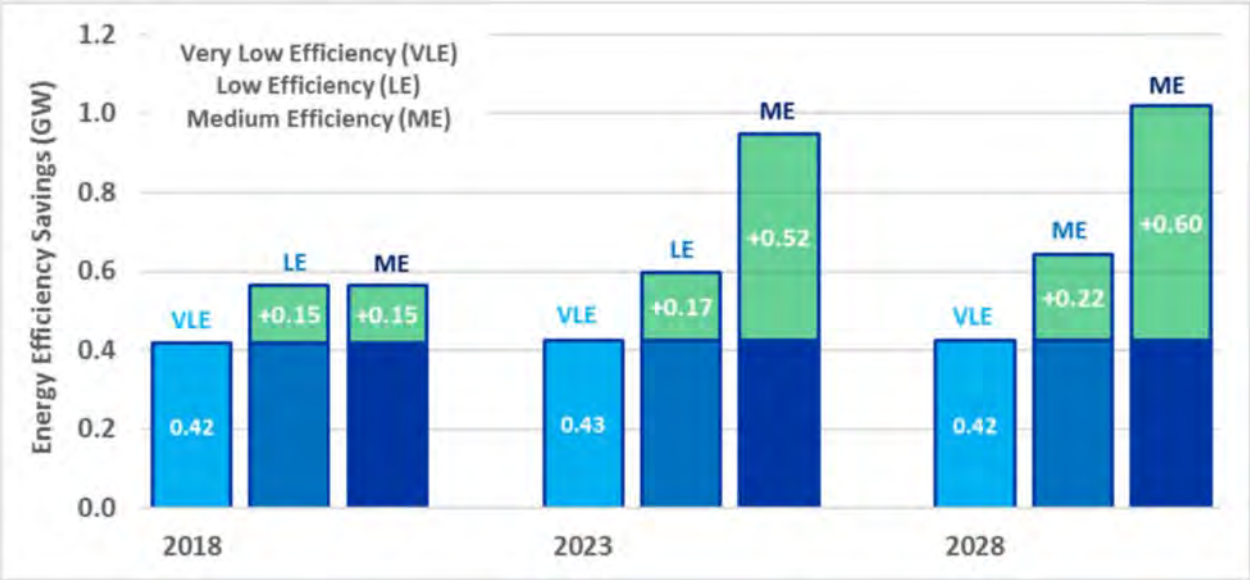


Note: *The total height of each column (including the green portion) is the value for that scenario in that year.*

[14] Absolute data can be found in Table 2 in the Appendix to this document.

The green sections show the delta or change from the Very Low Efficiency scenario value, and the labels in the green sections are the amounts of these deltas. A table with all results in absolute terms (the total heights of the columns) is presented in an Appendix to this report.

Figure 5. Virginia DEV net energy efficiency savings at peak (GW)



While the figures throughout this report show differences between scenarios in 2018, it should be noted that our historical data end in 2016. This means that both 2017 and 2018 data are projections, based on forecasts made by Dominion in 2015 and 2016. Energy sector data typically do not become available until one to two years after the fact: for example, actual 2017 data may not be available until 2018 or even 2019.

In its IRP, DEV forecasts 0.4 GW, 2.0 GW, and 4.0 GW cumulative (total over time) natural gas capacity additions in 2018, 2023, and 2028, respectively (see Table 1). The Low Efficiency and Medium Efficiency scenarios require fewer additions of new natural gas power plants. Fewer capacity additions result in a benefit for customers because the costs of new infrastructure are passed on to ratepayers, and expanded energy efficiency programs are less expensive for consumers than new DEV power plants.

Table 1. Natural gas capacity additions in Very Low Efficiency (VLE), Low Efficiency (LE) and Medium Efficiency (ME) scenarios (GW)

	2018	2023	2028
Very Low Efficiency	0.4	2.0	4.0
Low Efficiency	0.0	2.0	3.5
Medium Efficiency	0.0	1.7	1.7

Figure 6 reports the difference in natural gas capacity additions, respectively, between the Low Efficiency and Medium Efficiency scenarios and the Very Low Efficiency scenario. Figure 7 shows the change in natural gas generation in GWh between the Very Low Efficiency scenario and the other two scenarios. Figure 6 and Figure 7 can be compared to 2016 actual values of 7.5 GW and 27,700 GWh of natural gas capacity and generation.

Figure 6. Virginia DEV net natural gas capacity resources (GW)

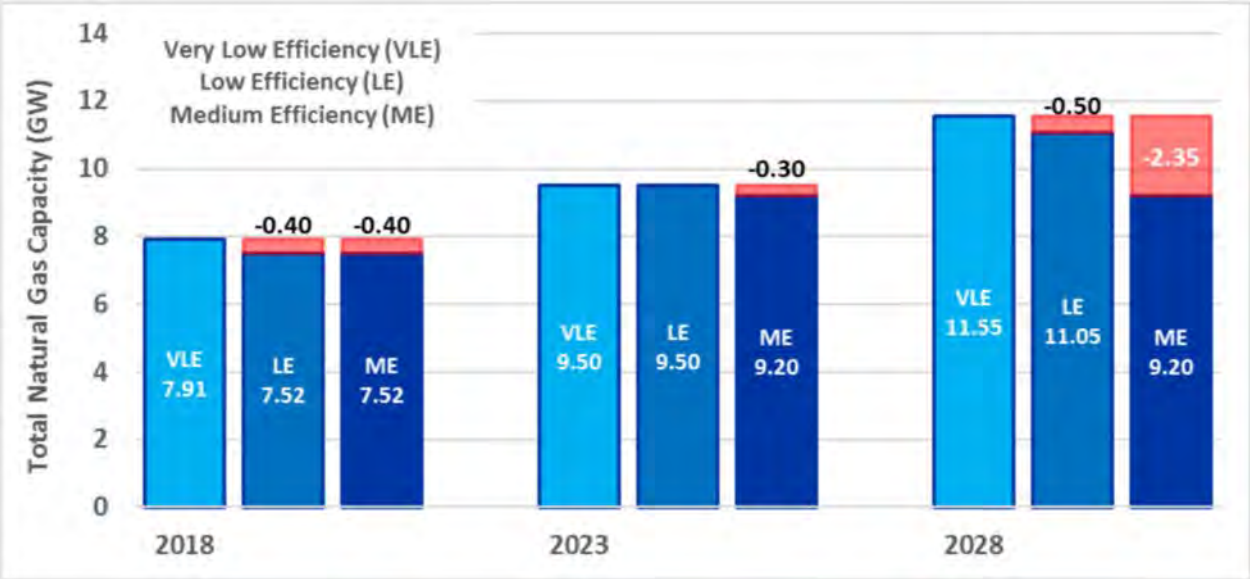
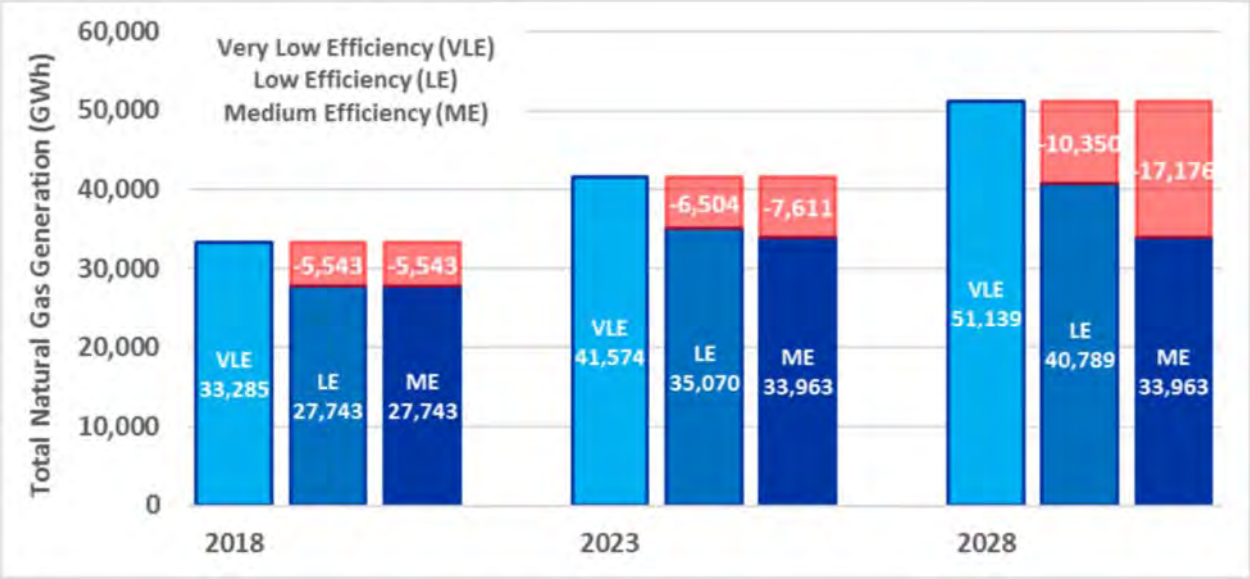


Figure 7. Virginia DEV net natural gas generation (GWh)

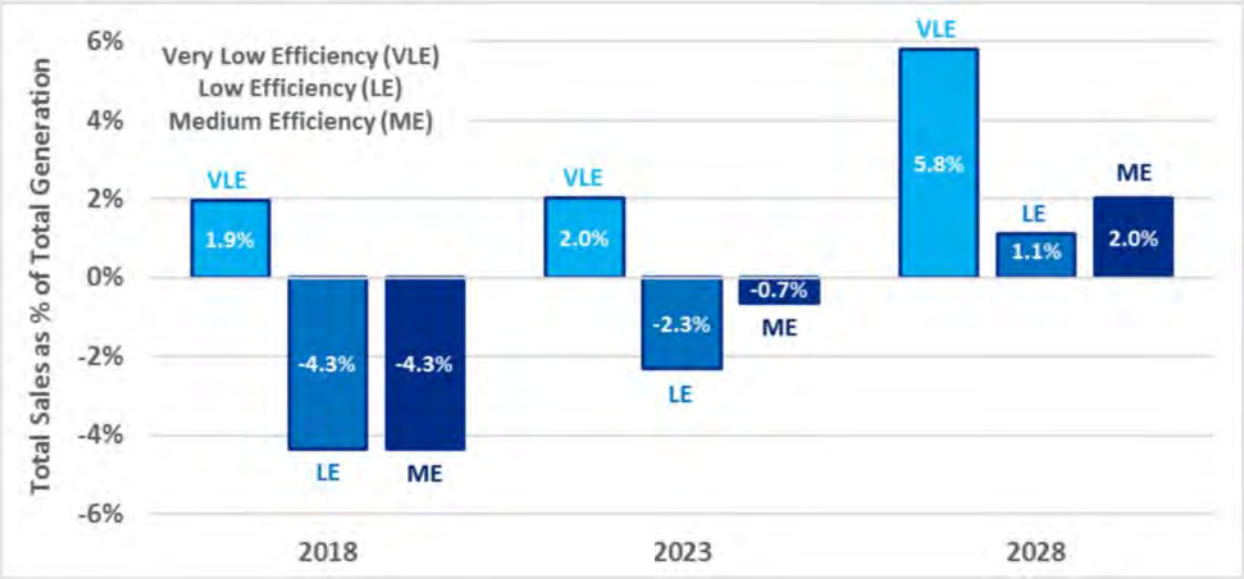


We assumed, for simplicity, that regardless of investments in efficiency or new capacity, the average hours of operation per year by generation type (capacity factor) would follow the Dominion IRP. Instead of decreasing generation in response to excess capacity we assume that DEV increases its sales to other utilities (off-system sales), as it does currently when it has excess capacity. Figure 8 shows DEV's off-system total sales as a percentage of total generation.[15] As shown in Figure 8, annual off-system sales or purchases between 2018 and 2028 are 6 percent or less of total generation. High off-system sales in the Very Low Efficiency scenario occur even though DEV is projecting much higher customer sales than expected by the Energy Information Administration (EIA): DEV's IRP capacity additions appear to greatly exceed its expected demand for electricity. Indeed, reserve capacity in the Very Low Efficiency scenario is 16.3 percent in 2018, as compared to the required minimum value of 12.5 percent.

We do not assume any additional retirements (other than those in DEV's IRP), and we only curtail natural gas investments.

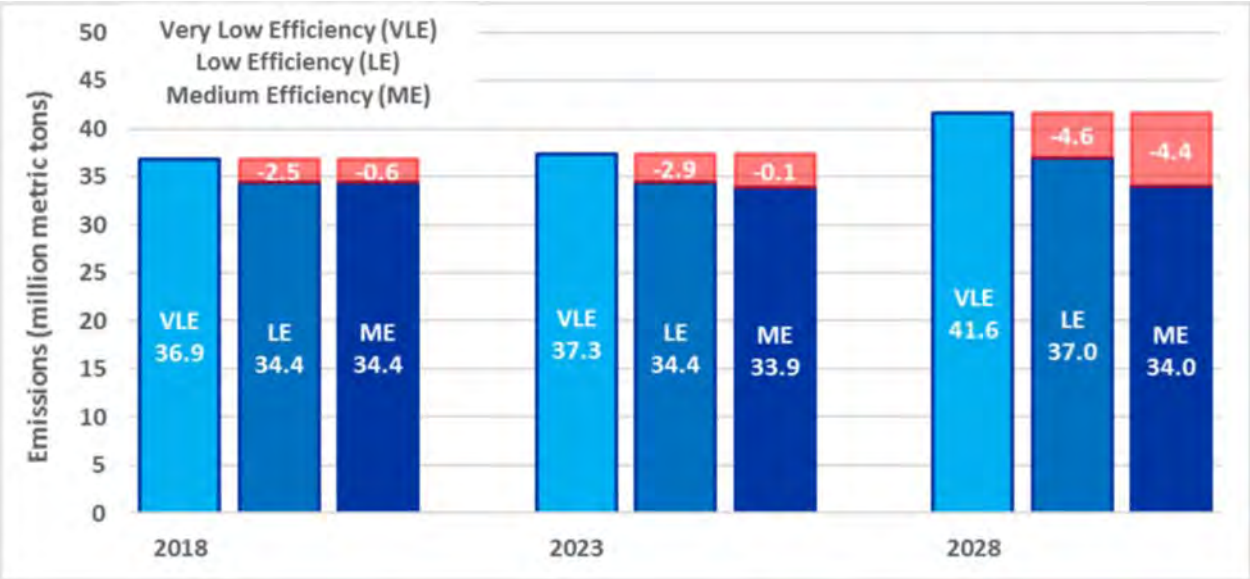
[15] On-system sales represent sales to customers to meet demand, while off-system sales occur once customer demand has been fulfilled, and represent sales to other utilities.

Figure 8. Virginia DEV net off-system sales as share of total generation (GWh)



Greater energy efficiency savings combined with constraints on how many new natural gas plants can be avoided (due to the need for reserves to fulfill peak demand) result in surplus generation for DEV. Less natural gas generation results in lower greenhouse gas emissions. If DEV were to reduce generation rather than sell excess within the PJM region, emissions declines would be even greater. While Figure 9 shows the change in carbon dioxide emissions from all of DEV's generation, including the emissions of DEV's off-system sales, an inventory of emissions could also be made based on DEV's sales to its own customers (on-system sales).

Figure 9. Virginia DEV carbon dioxide emissions (million metric tons)



Note: *Emissions shown here are for all DEV generation, including emissions associated with net off-system sales.*

Rates and Bills

Energy efficiency measures carry administrative and program costs that are passed on to customers through their electric rates.[16] These same efficiency measures also lower system-wide electricity costs in many ways, including reducing operations and maintenance costs (such as fuel) at existing power plants, deferring or avoiding the need for new generation assets, deferring or avoiding the need for new transmission and distribution assets, and more. The net effect of additional efficiency savings on rates can be either positive or negative depending on the components captured. Any increase in rates resulting from the need to recover costs associated with energy efficiency programs is generally offset by avoided costs of generation, transmission, and distribution. In some states, electric utilities may request recovery of lost revenues due to decreased sales, which can lead to a net increase in rates.[17] However, this has not been the case in Virginia thus far.[18]

Our analysis of residential electric rates in Virginia found that average customer energy usage, energy costs, and bills decrease with greater energy efficiency savings (Figure 10 and Figure 11).

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[16] In DEV's most recent DSM docket before the VA State Corporation Commission (SCC), Case No PUE-2016-00111, testimony from Jeffrey Loiter of Optimal Energy concludes that DEV could achieve additional energy efficiency savings by increasing the participation rates in its approved programs. Loiter calculates that if DEV "had reached at least the planned level of participation for each program (but still over-achieved in the Residential Home Energy Check-up and Non-Residential Duct Testing and Sealing Program), total savings through 2015…would be between 50 and 75% greater than the actual results." Loiter also targets central air conditioning (CAC) and heat pump savings as the most prominent area of energy efficiency potential that DEV is not capturing. He suggests that it pursue conversions from baseboard heat to ductless heat pumps, an integrated approach to maintenance and upgrades of existing CAC and heat pump systems (including ductwork), and building shell improvements for heat pump customers as part of a broader, more aggressive energy efficiency strategy. Testimony available at: http://www.scc.virginia.gov/docketsearch/DOCS/3d4%2501!.PDF

[17] Woolf, T., Malone, E. and C. Neme. 2014. Regulatory Policies to Support Energy Efficiency in Virginia. Prepared for the Virginia Energy Efficiency Council. Page 14. Available at: http://www.synapse-energy.com/sites/default/files/Regulatory%20Policies%20to%20Support%20Energy%20Efficiency%20in%20Virginia%2014-110.pdf

[18] In Virginia, utilities may request recovery of lost revenues from the State Corporation Commission (SCC). Dominion has seldom requested and has never been granted lost revenue recovery and we have not included lost revenues as a rate component in this analysis.

Figure 10. Average Virginia DEV residential customer annual energy use, 2017-2032

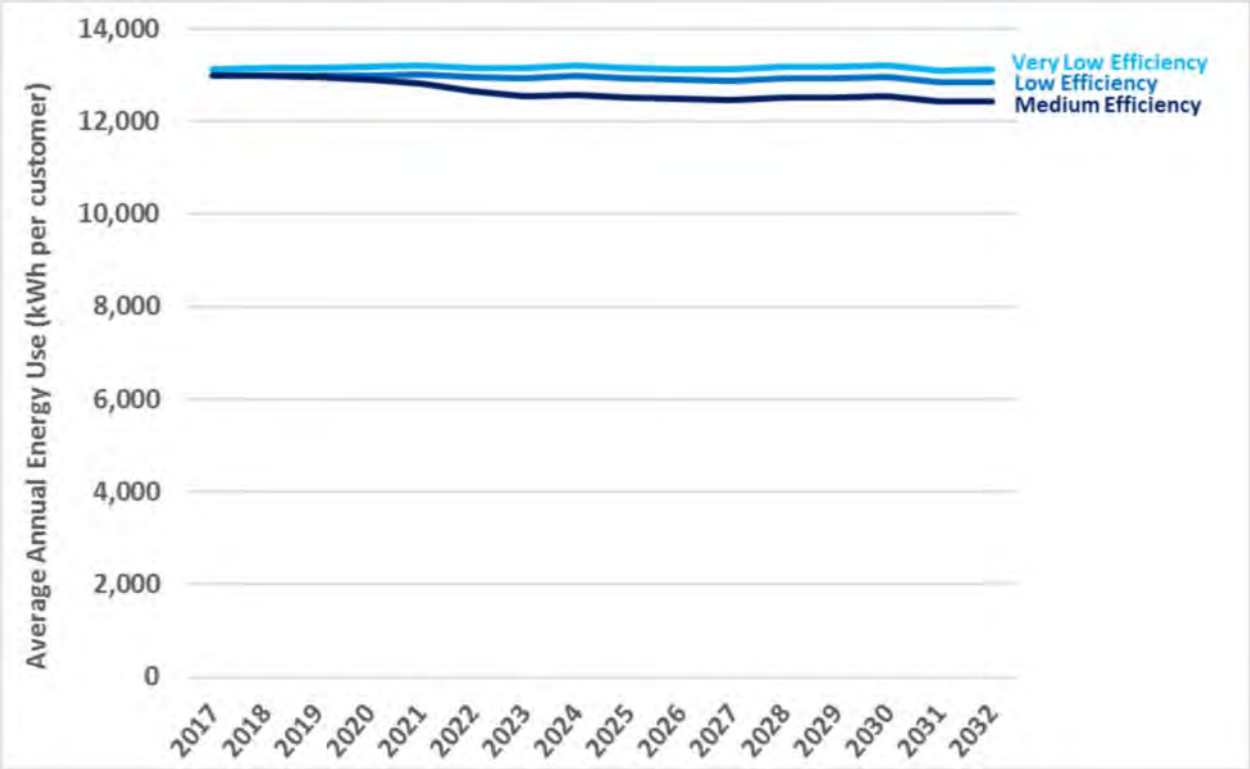
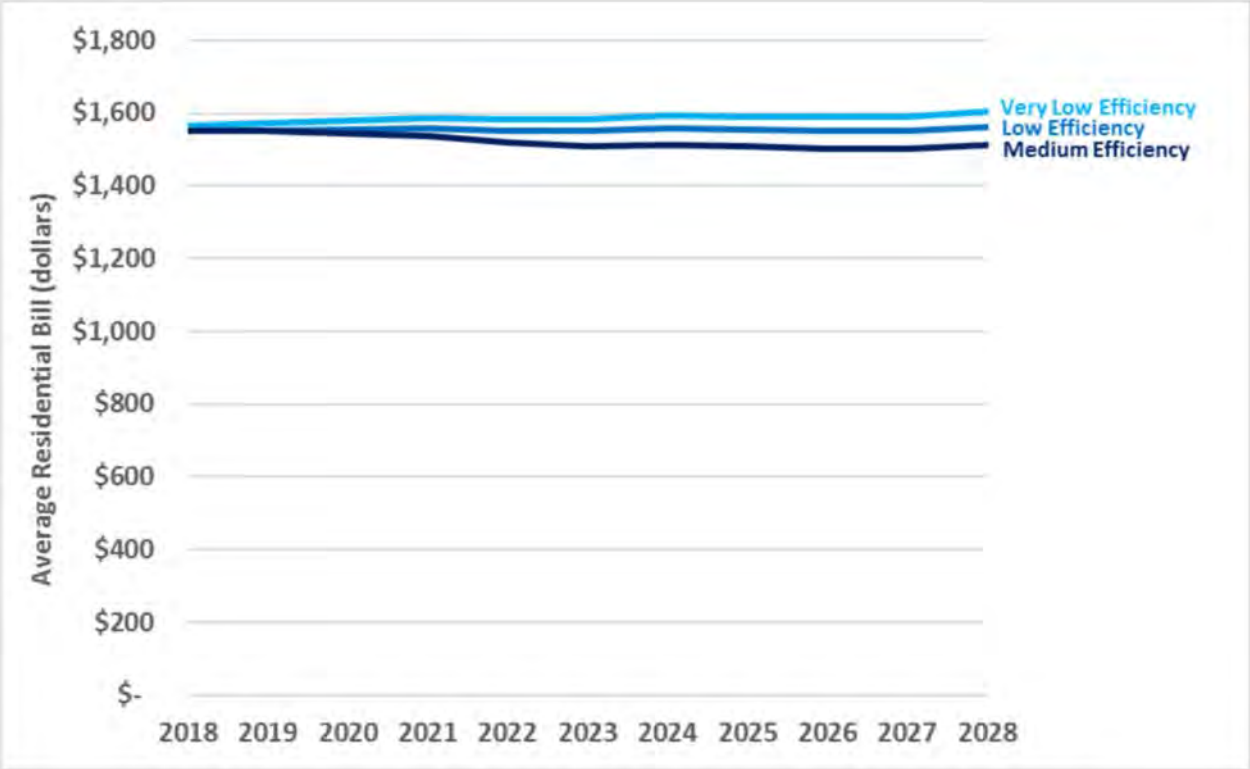


Figure 11 shows average annual customer bills in the three scenarios. Customer bills increase over time with Very Low Efficiency forecasted levels of electric sales and energy efficiency. Bills are lower in the Low Efficiency scenario and lower still in the Medium Efficiency scenario. Compared to the Very Low Efficiency scenario in 2028, the average DEV residential customer's annual bill is $41 less expensive under the Low Efficiency scenario; and $92 less expensive under the Medium Efficiency scenario. Cumulatively, from 2018 through 2028, Dominion customer bill savings total $800 million to $1.7 billion.

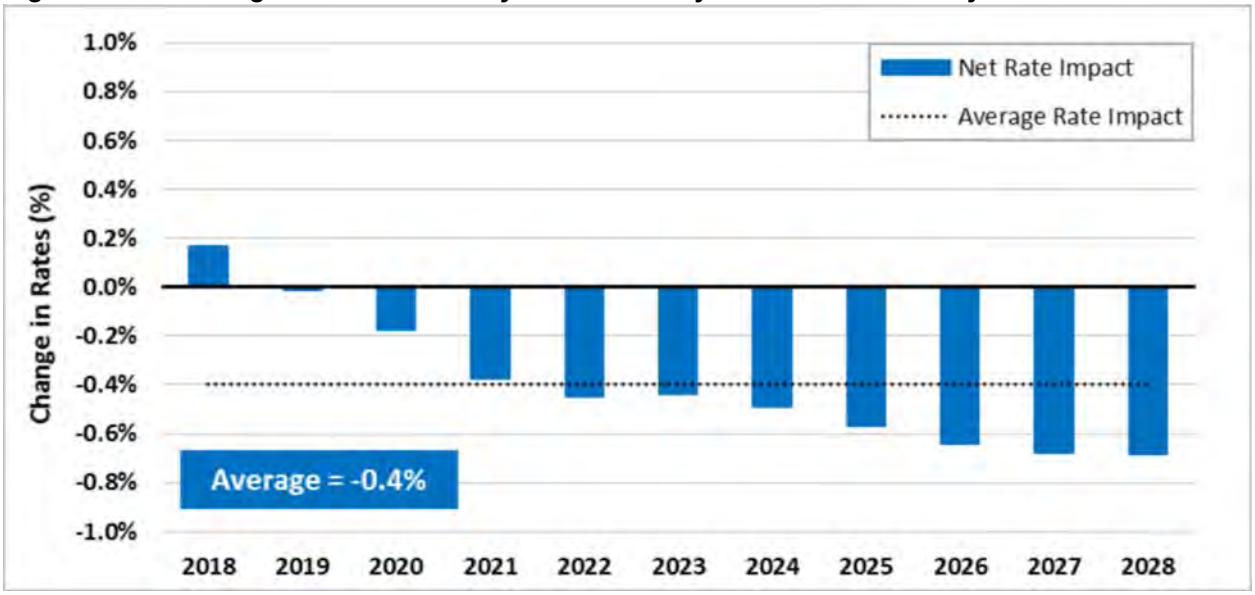
Figure 11. Average annual Virginia DEV residential electric bills



The most aggressive efficiency case considered delivers a 5.74 percent average reduction in consumer electricity bills in 2028. The next most aggressive efficiency case cuts bills by 1.96 percent. Most of these savings result from lower energy use, while a smaller portion is driven by changes in customer rates.

Utility charges to consumers resulting from increased energy efficiency are outweighed by the savings associated with the avoided capacity, transmission, and distribution. When efficiency savings are increased from the Very Low Efficiency scenario to the Low Efficiency scenario, customers see a small rate increase (but not a higher bill) in the first year of the analysis period as energy efficiency program costs are raised. In the second year and beyond, the avoided costs of capacity, transmission, and distribution outweigh the costs of energy efficiency and lead to a decline in residential rates, with an average rate impact over the ten-year period of -0.4 percent, and -0.7 percent in 2028 (Figure 12).

Figure 12. Net change in rates from Very Low Efficiency in the Low Efficiency scenario



When efficiency savings are increased from the Very Low Efficiency scenario to the Medium Efficiency scenario, customers see a slightly smaller decline in rates over the analysis period, with an average impact on residential rates over the period of -0.3 percent, and -0.8 percent in 2028 (Figure 13).

Figure 13. Net change in rates from Very Low Efficiency in the Medium Efficiency scenario

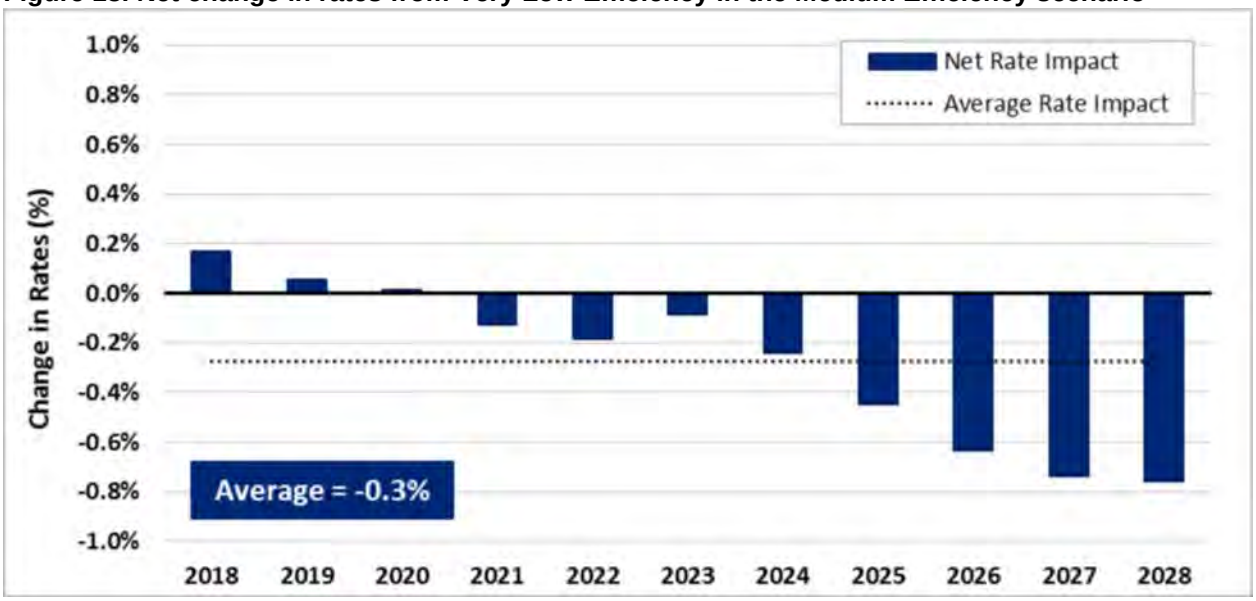
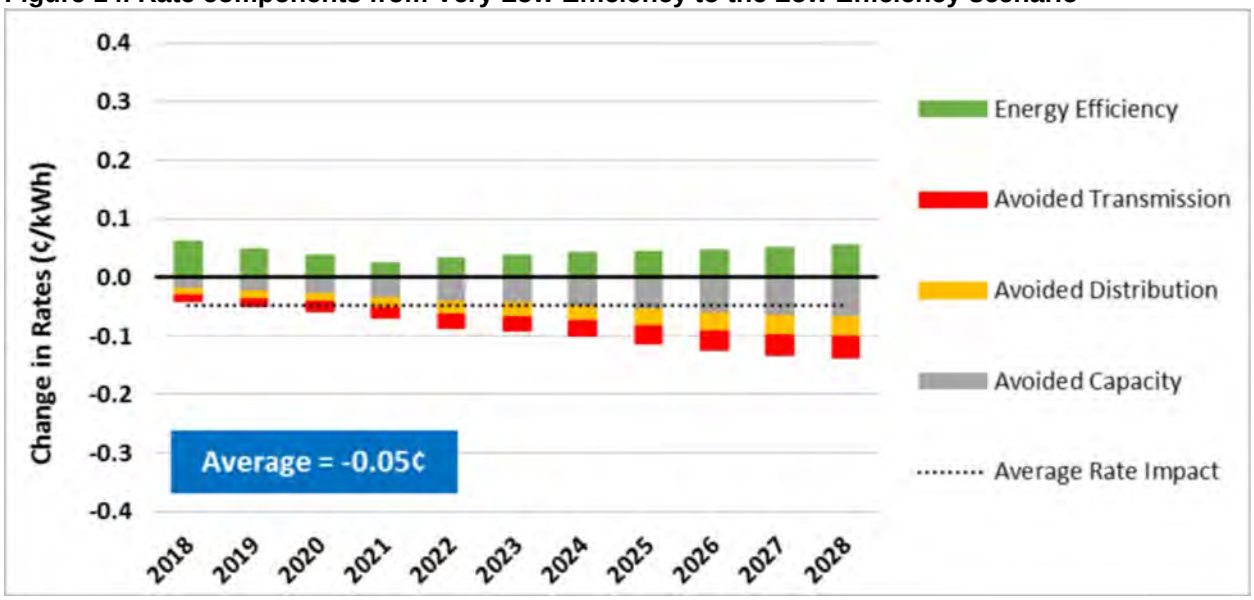


Figure 14 and Figure 15 show changes in customer rates by individual rate component. Avoided capacity costs grow most dramatically over the analysis period, and when combined with the cost

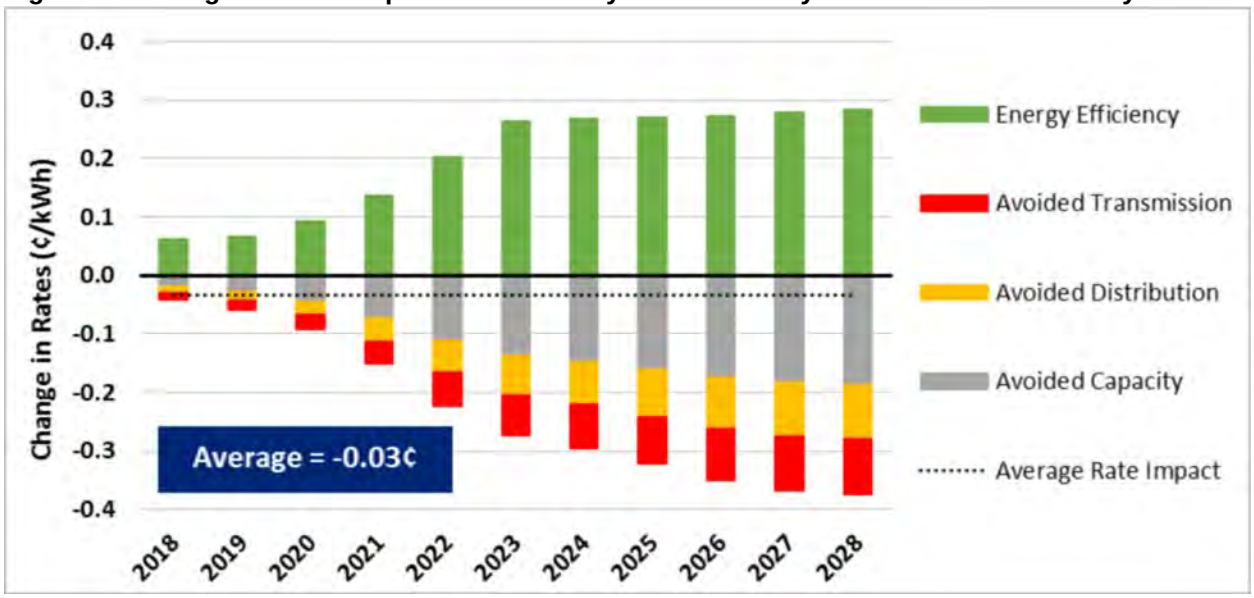
associated with avoided transmission and distribution, the savings to residential customers outweigh the costs associated with energy efficiency charges and lost transmission/distribution revenues that are recovered by DEV. An increase in energy efficiency that allows achievement of Virginia's EERS goal in 2020 would result in an average residential bill cost savings of 0.05 cents/kWh between 2018 and 2028, and 0.08 cents/kWh in 2028 (see Figure 14).

Figure 14. Rate components from Very Low Efficiency to the Low Efficiency scenario



An increase in energy efficiency to the level of a utility like Eversource in Massachusetts (as in the Medium Efficiency scenario) would result in an average residential bill cost savings of 0.03 cents/kWh between 2018 and 2028, and 0.09 cents/kWh in 2028 (see Figure 15).

Figure 15. Change in rate components from Very Low Efficiency to the Medium Efficiency scenario

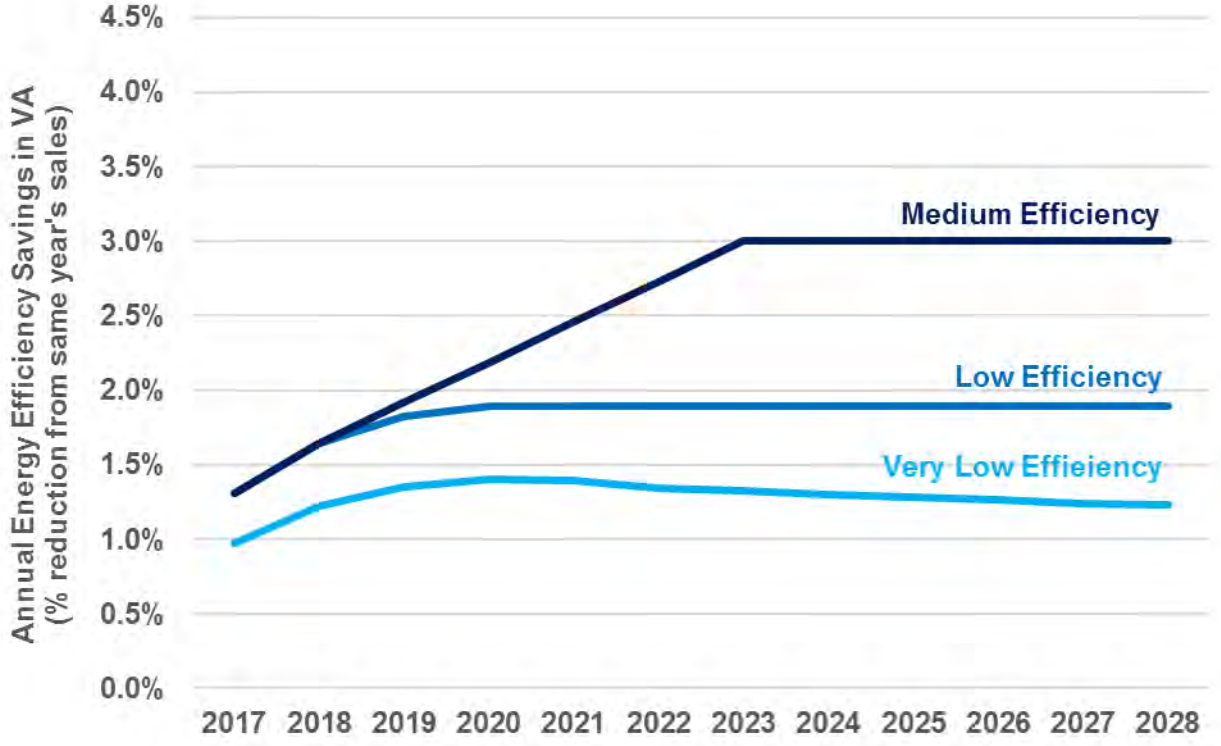


III. Methodology and Assumptions

We used a simple spreadsheet methodology to construct three scenarios of capacity, generation, and emissions by resource type, as well as costs and rates across all resource types, from 2018 to 2028 using different sets of assumptions regarding future energy efficiency savings: Very Low Efficiency, Low Efficiency and Medium Efficiency (see Figure 16 below).

We constructed the Very Low Efficiency scenario using information exclusively from Dominion's 2017 IRP, making no adjustments. The Very Low Efficiency scenario results in excess capacity, which is acknowledged in DEV's IRP document. The Low Efficiency scenario and Medium Efficiency scenarios differ from the Very Low Efficiency scenario in their amount of energy efficiency. In the Low Efficiency and Medium Efficiency scenarios, to balance sales with generation while maintaining Dominion's coincident capacity reserve requirement of 12.5 percent, we adjust natural gas capacity additions in 2018, 2023 and 2028. The input assumptions for our Low Efficiency and Medium Efficiency scenarios adjust DEV's summer peak energy use projections in proportion to the Dominion IRP forecasted sales growth. Figure 16 presents the energy efficiency savings, as a percent of annual sales, modeled in the Very Low Efficiency, Low Efficiency, and Medium Efficiency energy efficiency scenarios through 2028.

Figure 16. Annual incremental energy efficiency savings in each DEV energy efficiency scenario



All three scenarios meet Virginia's voluntary Renewable Energy Portfolio Goal. In 2007, Virginia enacted a voluntary renewable goal for investor-owned electric utilities (IOUs) to provide 15

percent of electric energy sales from renewable sources annually by 2025 (from a 2007 baseline). While Virginia's renewable goal is not compulsory, it does require IOUs to report on their efforts to meet the goal.[19] Under the renewable goal, IOUs are not required to account for each MWh of energy with a Renewable Energy Credit (REC), nor are MWh savings required to occur in Virginia, as is common in other state's Renewable Portfolio Standard (RPS) programs.[20] State Senator Donald McEachin (D) introduced legislation in 2016 to amend the goal to become mandatory, but the legislation was not been passed.[21]

DEV's residential electric rates are made up of five different charge components: a fixed customer charge of $7, and charges for energy efficiency, generation, transmission, and distribution on a cents/kWh basis. The fixed customer charge remains constant over the three scenarios analyzed in this report. The change in charges between scenarios was determined by dividing annual program cost to ratepayers by annual efficiency savings. We determined annual program cost by multiplying DEV's cost of saved energy in $/MWh (calculated as total program costs divided by total energy savings) with the annual saved energy values calculated for the Low Efficiency and Medium Efficiency scenarios.

To estimate changes to residential electric rates under the Low Efficiency and Medium Efficiency scenarios, we calculated the impact that the increased energy and demand savings would have on the individual components that make up residential rates, obtained from DEV's current rate schedule.[22] Total costs to residential consumers of generation, transmission, and distribution were calculated under each of the scenarios based on the volume of sales in that scenario. Avoided costs were calculated as a function of efficiency savings. Individual charges for generation, transmission, and distribution (taking account of avoided costs due to efficiency) were then calculated for all three scenarios: Very Low Efficiency, Low Efficiency and Medium Efficiency.

Costs and Benefits Not Covered in This Report

This analysis focused on the impacts of energy efficiency on consumer bills, utility rates, the need for new generating capacity, and emissions. Costs and benefits associated with energy efficiency improvements not covered by this report include the cost of energy efficiency improvements not

[19] DSIRE, Virginia Voluntary Renewable Energy Portfolio Goal, Updated February 8, 2015, http://programs.dsireusa.org/system/program/detail/2528.
[20] Chesapeake Climate Action Network, Virginia's Renewable Portfolio Standard: Utilities Receive Millions in Bonuses for Business as Usual?, October, 2012, http://chesapeakeclimate.org/wp/wp-content/uploads/2012/10/RPS-Backgrounder-10-2012.pdf.
[21] Virginia's Legislative Information System, SB 761, January 22, 2016, https://lis.virginia.gov/cgi-bin/legp604.exe?161+ful+SB761+pdf.
[22] Virginia Electric and Power Company, Rate Schedule, Revised October 1, 2017, https://www.dominionenergy.com/.

covered by utilities and the added consumer benefits that arise from efficiency measures, such as improved home safety and comfort, water conservation, and the societal health and economic benefits of reducing criteria and greenhouse gas pollutants from power plants.

Inputs

What follows is a list of the inputs used in our spreadsheet analysis and their sources:

Capacity

- Data for historical years 2005 and 2010 come from EIA 860 data and include all values for "Dominion Virginia Power" in 2005 and "Virginia Electric and Power Co" in 2010 (including both VA and NC).

- Data for historical and future years 2014-2028 come from Dominion's 2017 IRP, Appendix 3F, pp.185.

    - Dominion's IRP does not distinguish between types of renewables in future years. All historical renewable capacity through 2016 comes from biomass. To distinguish between types of renewables (biomass, wind and solar) included in Dominion's future resource portfolio, we did the following:

        - Assume that the 2016 biomass capacity (236 MW) continues unchanged into the future.

        - To determine future wind and solar capacity, sum the 2017 solar and 2021 wind additions, as listed in the IRP (for 2018 and 2023, respectively).

        - To determine the remaining future solar and wind capacity figures (solar for 2023 and 2028 and wind for 2028), take the total renewable capacity for 2023 and 2028 as listed in the IRP Appendix 3F and subtract the figures for biomass, solar and wind as relevant.

        - This ensures that our total renewable capacity figures for biomass, wind and solar in 2018, 2023 and 2028 match the total renewable capacity figures listed in the IRP Appendix 3F.

- Data for "DSM Peak Reduction" come from Dominion's 2017 IRP, Appendix 3N, pp.200 adjusted to rise in direct proportion to annual energy efficiency projections by scenario.

- Natural gas capacity is the balancing factor in our modeling. For each scenario, we reduce capacity additions in each future year in 100 MW blocks until the last level that maintains an adequate peak coincident reserve requirement, as defined in Dominion's 2017 IRP, Section

4.2, Figure 4.2.2.1, pp.67.

Capacity factors

- Solar and wind capacity factors come from Dominion's 2017 IRP, Appendix 3D, pp.182.
- All other capacity factors are calculated from Dominion's 2017 IRP historical generation and capacity levels.

Generation

- Data for years 2005 and 2010 come from EIA Form 923 data and include all values for "Dominion Virginia Power" in 2005 and "Virginia Electric and Power Co" in 2010 (including both VA and NC).
- Data for years 2014-2016 come from Dominion's 2017 IRP, Appendix 3G, pp.186 (following the same exception for renewables described above regarding capacity).
- "Pumped Hydro Storage" includes both "Hydro Pumped Storage" (line i) and "Less Pumping Energy" (line n) from the IRP Appendix 3G, pp. 186.
- Generation is calculated for each year and scenario as capacity multiplied by 8,760 hours multiplied by capacity factor.

Energy and peak

- Historical "Annual (reconstituted) sales" data come from EIA Form 861 data for all "Virginia Electric and Power Co" (including both VA and NC).
- Forecasted sales data is obtained from Dominion's 2017 IRP, Appendix 2B, pp. 158.
- Data for "Utility Summer Peak Load (adjusted)" come from the "Summer Peak, Adjusted Load" values from Dominion's 2017 IRP, Appendix 2H, pp.164.
- For the forecasted "Utility Summer Peak Load (adjusted)" figures, multiply the 2016 figure by the ratio of growth in sales and growth in peak from 2016-2018 defined in Dominion's 2017 IRP;
- Repeat the same process between 2018-2023 and 2023-2028.
- Data for coincident peak reserve requirement come from Dominion's 2017 IRP, Section 4.2, Figure 4.2.2.1, pp.67.

Emissions Rate

- Emissions rates are technology-specific and are calculated based on EIA Form 923 data for Virginia. We use the 2015 emissions rates throughout the future period modeled.

Emissions

- Emissions are the product of emissions rates multiplied by generation.

Expected Retirements and Additions

- Expected retirements and additions are obtained from EIA Form 860 data and from Dominion's 2017 IRP, Section 3.1, Figure 3.1.5.1, pp.41.

Electric Rates

- Sales data come from Dominion's 2017 IRP, Appendix 2B, pp. 158.
- Customer counts come from Dominion's 2017 IRP, Appendix 2E, pp. 161.
- Annual energy savings and lifetime energy savings data come from Dominion's 2017 IRP, Appendix 5E, pp. 235.
- Annual demand savings data come from Dominion's 2017 IRP, Appendix 3O, pp. 201.
- Rate information comes from the Virginia Electric and Power Company Filed Tariff, Revised 10-01-17.
- Dominion's cost of saved energy, in $/MWh is calculated by dividing reported costs of energy efficiency by reported savings.[23]
- Avoided costs are estimated at $30/MWh for energy, $50/kW for capacity, and $25/kW for transmission and distribution.

[23] Dominion's 2016 electric sales, as reported in its 2017 IRP, are multiplied by its customer conservation charge to arrive at the total cost of its energy efficiency programs. This cost is then divided by reported efficiency savings to arrive at the cost of saved energy.

Appendix

Table 2. Findings by scenario

	Very Low Efficiency			Low Efficiency			Medium Efficiency		
	2018	2023	2028	2018	2023	2028	2018	2023	2028
Total Demand Side Management (DSM) (GWh)	1,036	1,214	1,197	1,380	1,709	1,813	1,380	2,673	2,840
Total DSM (GW)	0.42	0.43	0.42	0.56	0.60	0.64	0.56	0.95	1.02
Total Natural Gas Combined Cycle (NGCC) capacity (GW)	7.91	9.50	11.55	7.52	9.50	11.05	7.52	9.20	9.20
Total NGCC generation (GWh)	33,285	41,574	51,139	27,743	35,070	40,789	27,743	33,963	33,963
Total off-system sales (GWh)	1,601	1,810	5,700	-9	1,902	5,358	-9	3,265	6,003
Emissions (million metric tons)	36.85	37.31	41.59	36.26	37.71	40.24	36.26	37.22	37.22

Attachment 3

COMMONWEALTH OF VIRGINIA

STATE CORPORATION COMMISSION

AT RICHMOND, DECEMBER 7, 2018

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COMMONWEALTH OF VIRGINIA, *ex rel.*

STATE CORPORATION COMMISSION

CASE NO. PUR-2018-00065

In re: Virginia Electric and Power Company's
Integrated Resource Plan filing pursuant to
Va. Code § 56-597 *et seq.*

ORDER

On May 1, 2018, Virginia Electric and Power Company ("Dominion" or "Company") filed with the State Corporation Commission ("Commission") the Company's 2018 Integrated Resource Plan ("IRP") pursuant to § 56-597 *et seq.* of the Code of Virginia ("Code"). Dominion's 2018 IRP encompasses the planning period from 2019 to 2033.

On May 7, 2018, the Commission issued an Order for Notice and Hearing in this proceeding that, among other things, established a procedural schedule; set an evidentiary hearing date; directed Dominion to provide public notice of its IRP; and provided any interested person an opportunity to file comments on the Company's IRP, or to participate in the case as a respondent by filing a notice of participation. Notices of participation were filed by Appalachian Voices ("Environmental Respondents"); the Virginia Chapter of the Sierra Club ("Sierra Club"); the Board of Supervisors of Culpeper County, Virginia ("Culpeper County"); the Mid-Atlantic Renewable Energy Coalition ("MAREC"); the Solar Energy Industries Association ("SEIA"); the Virginia Committee for Fair Utility Rates ("Committee"); Sandra L. Meyer, Trustee of the Meyer Family Trust ("Meyer Trust"); and the Virginia Office of the Attorney General, Division of Consumer Counsel ("Consumer Counsel").

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The Commission's Order for Notice and Hearing also provided for the pre-filing of testimony and exhibits by Dominion, respondents and the Commission's Staff ("Staff"). The Company, Environmental Respondents, Sierra Club, MAREC, and Staff pre-filed testimony in this proceeding.

On September 7, 2018, Dominion filed a Motion *in Limine* ("Motion"). On September 21, 2018, the Environmental Respondents filed a response in opposition to Dominion's Motion. On October 5, 2018, Dominion filed its reply.

Beginning on September 24, 2018, the Commission convened a hearing on the Company's 2018 IRP.[1] During the hearing, the Commission received the testimony of public witnesses.[2] The Commission also received testimony and exhibits from Dominion, the respondents, and Staff.[3] The hearing concluded, after closing arguments, on September 27, 2018.

NOW THE COMMISSION, upon consideration of this matter, is of the opinion and finds as follows.

Pursuant to § 56-599 C of the Code, the Commission must, after giving notice and an opportunity to be heard, determine whether Dominion's IRP is reasonable and in the public interest. For the reasons discussed below, the Commission finds, based on the record of this proceeding and applicable statutes, that the Company has failed to establish that its 2018 IRP, as

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[1] Staff and all parties except Culpeper County, the Committee, and the Meyer Trust participated in the hearing.

[2] Tr. 12-50. The Commission also received public comments filed pursuant to the Order for Notice and Hearing.

[3] At the hearing, the Commission noted that it would rule on the Motion in its Final Order in this proceeding. Tr. 9. We deny any objections we took under advisement and admit the testimony of Environmental Respondents witness Lander (Ex. 22). As noted during the hearing, admission of an exhibit is not tantamount to a finding of fact. Findings of fact are contained in orders as such. Tr. 10-11. The Motion is denied.

currently filed, is reasonable and in the public interest. The Commission further finds that the Company shall correct and refile its 2018 IRP subject to the provisions of this Order.

Compliance with Prior Commission Order

In its Order on Dominion's 2017 IRP,[4] the Commission took judicial notice of Senate Bill 966,[5] recognizing that the new legislation would impact subsequent IRPs. The Commission directed "that Dominion's future IRPs, beginning with the IRP due to be filed on May 1, 2018, shall include detailed plans to implement the mandates contained in that legislation, as well as plans that comply with all other legal requirements."[6] The Commission noted "[t]his includes, for example, the utility's least-cost plan along with plans compliant with proposed federal carbon-control regulations . . . ."[7]

The record in the instant proceeding reflects that the Company's least-cost plan includes resources, such as the Coastal Virginia Offshore Wind ("CVOW") demonstration project, that were not selected by the Company's modeling on a least-cost basis, but rather were forced into each of the Company's alternative plans.[8] The record also reflects that the Company's modeling was not permitted to select certain highly-efficient natural gas-fired combined-cycle facilities for

---

[4] *Commonwealth of Virginia, ex rel. State Corporation Commission, In re: Virginia Electric and Power Company's Integrated Resource Plan filing pursuant to Va. Code § 56-597 et seq.*, Case No. PUR-2017-00051, Doc. Con. Cen. No. 180320095, Order (Mar. 12, 2018) ("2017 IRP Order").

[5] 2018 Acts ch. 296.

[6] 2017 IRP Order at 3-4.

[7] *Id.* at 4 n.8. The Commission also explicitly required the Company to include a least-cost plan as part of its 2017 IRP. *See Commonwealth of Virginia, ex rel. State Corporation Commission, In re: Virginia Electric and Power Company's Integrated Resource Plan filing pursuant to Va. Code § 56-597 et seq.*, Case No. PUE-2016-00049, 2016 S.C.C. Ann. Rept. 405, 407 (Dec. 14, 2016).

[8] *See, e.g.*, Ex. 37 (Abbott) at 7 n.3; Tr. 601.

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purposes of developing a least-cost plan.[9] Forcing in higher-cost resources and excluding other lower-cost resources results in a more expensive least-cost plan. While there may be appropriate or defensible reasons, including review of various potential state and federal carbon restrictions, for Dominion to include the scenarios it chose for the IRP, omitting a true least-cost plan does not provide the analysis needed to assess the incremental cost of various options, for Commission analysis, and for statutorily required reporting to the General Assembly. Based on the foregoing, the Commission finds that the Company did not comply with the Commission's directive to include a least-cost plan in its 2018 IRP.

With respect to the requirement to address the mandates contained in Senate Bill 966, the record reflects that the Company included some, but not all, of those mandates in its 2018 IRP. For example, the Company's plans include CVOW as well as solar photovoltaic ("PV") resources ranging in amounts up to 6,640 megawatts ("MW").[10] The Company did not, however, model $870 million in energy efficiency programs, nor did it model a battery storage pilot required by Senate Bill 966.[11] The 2018 IRP also did not include costs associated with the Company's Strategic Undergrounding Program ("SUP"), Grid Transformation Plan, or Transmission Line Undergrounding Pilot, each of which was contained in, or modified by, Senate Bill 966.[12] Again, by omitting certain mandates the IRP as filed does not provide the analysis and back-up data needed to assess the cost of these mandates, for Commission review, and for statutorily required reporting to the General Assembly. Based on the foregoing, the Commission further

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[9] *See, e.g.*, Ex. 31 (Samuel) at 17; Ex. 37 (Abbott) at 7.

[10] *See, e.g.*, Ex. 37 (Abbott) at 5.

[11] *See, e.g.*, *id.*; Ex. 24 (Hausman) at 20, 22-23; Tr. 139-140, 164.

[12] *See, e.g.*, Ex. 37 (Abbott) at 6.

finds that the Company's 2018 IRP did not fully comply with the Commission's prior directive to include detailed plans to implement the mandates contained in Senate Bill 966.[13]

Corrected 2018 IRP

The Commission finds that the Company shall re-run and re-file the corrected results of its 2018 IRP within 90 days from the date of this Order, subject to the requirements of this Order.

In its corrected 2018 IRP, for purposes of its least-cost plan, the Company shall not force the modeling to select any resource, nor exclude any reasonable resource.[14] This requirement does not reflect any finding that the Company should pursue any specific resource included in the least-cost plan; rather, as the Commission has repeatedly recognized, the IRP is a planning document, and it is reasonable, for planning purposes, to identify the least-cost plan to provide a benchmark against which to measure the costs of other alternative plans.

As previously ordered, the Company shall also calculate the incremental cost impacts of the mandates contained in Senate Bill 966, including a comparison to the identified least-cost plan. This includes CVOW; 5,000 MW of nameplate wind and solar, including at least 25 percent of such resources from non-utility generators; $870 million in spending on energy efficiency programs; the 30 MW battery storage pilot; the SUP;[15] the Grid Transformation Plan; and the Transmission Line Undergrounding Pilot.

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[13] The Commission accepts the Company's explanation that it misunderstood the requirements set forth in the Commission's prior order, *see* Tr. 1003-1005, and the Commission does not find bad faith on the part of the Company.

[14] The record reflects that the Company did not include fuel transportation costs in the modeled costs of certain natural gas generation facilities. Tr. 610. For purposes of the corrected 2018 IRP, the Company should include a reasonable estimate of fuel transportation costs, including interruptible transportation, if applicable, associated with all natural gas generation facilities in addition to the fuel commodity costs.

[15] With respect to the SUP, the Company shall calculate the incremental cost impacts associated with those SUP conversions after September 1, 2016, that were not approved for recovery prior to the effective date of Senate Bill 966.

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In sum, while an IRP is a planning document and does not approve any specific expenditure, legally-mandated costs are likely to be borne by customers in one form or another, so it is essential that an IRP provide the public and policymakers with projected costs for such mandates that are as accurate as possible.

Load Forecast

The reasonableness of the Company's load forecast was a significant issue in this proceeding and the Commission received considerable evidence and argument related to the Company's load forecast. Several alternative load forecasts were presented by Staff and respondents for the Commission's consideration, each of which supported, to varying degrees, lower peak load and energy sales forecasts compared to the Company.[16] Notably, the Company's peak load and sales forecasts are higher than those of PJM,[17] the regional transmission entity of which the Company is a member, and the entity that sets the Company's capacity obligation within the PJM capacity market.[18] For example, the evidence showed that PJM's 2018 Load Forecast projects a peak demand 15-year compound annual growth rate ("CAGR") of 0.8% for the Dominion Zone of PJM, compared to the Company's internal forecast of 1.4%.[19] For energy, PJM projects a 15-year CAGR of 0.9% for the Dominion Zone, compared to the Company's

[16] *See, e.g.,* Ex. 20 (Wilson) at 10; Ex. 28 (McBride) Drilling Info Report at 29-34; Ex. 35 (White) at 14-15.

[17] PJM Interconnection, L.L.C.

[18] Tr. 737-38.

[19] Ex. 4 (IRP) at 17, 22.

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internal forecast of 1.4%.[20] The record further reflects that, since 2016, Dominion's forecast has begun to diverge significantly from PJM's forecast.[21]

The record further reflects that the load forecasts contained in the Company's past IRPs have been consistently overstated, particularly in years since 2012, with high growth expectations despite generally flat actual results each year.[22] For example, the evidence showed that the Company's 2012 IRP projected peak load of approximately 21,500 MW in 2017 whereas the actual peak was approximately 19,500 MW.[23] Moreover, for the past several years, the Company has generally lowered its expected base year forecast with each subsequent IRP, while maintaining a similar slope for its long term forecast.[24]

The Commission recognizes that every forecast has strengths and weaknesses and that no forecast will exactly match actual results except by chance; however, weighing the evidence presented in this proceeding, the Commission has considerable doubt regarding the accuracy and reasonableness of the Company's load forecast for use to predict future energy and peak load requirements. In reaching this conclusion, the Commission has considered all evidence presented in this proceeding including the alternative forecasts presented, as well as trends in the Company's historical load forecasts.

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[20] *Id.*

[21] Ex. 35 (White) at 13-14; Tr. 514.

[22] Ex. 20 (Wilson) at 4-5; Ex. 23 (Shobe) at 3-6; Ex. 28 (Drilling Info Report) at 36.

[23] *See, e.g.*, Ex. 54; Ex. 50 (Thomas Rebuttal) at 26. The evidence also showed, as another example, that the Company's 2015 IRP projected a 2018 peak that was 2,500 MW higher than the actual 2018 peak. Tr. 516.

[24] Ex. 35 (White) at 13.

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Based on the foregoing, rather than the Company's internal load forecast, the Commission directs that, for purposes of its corrected 2018 IRP, the Company shall utilize the Dominion Zone PJM coincident peak load forecast and energy sales forecast, scaled down to the Dominion load serving entity level, consistent with the methodology presented by Staff witness White, as further modified below.[25] The coincident peak is appropriate because, as Dominion acknowledges, PJM establishes the Company's capacity obligation based on Dominion's contribution to PJM's coincident peak.[26] Moreover, as acknowledged by the Company, one of the benefits of PJM membership is the capacity available to the Company for purchase from the PJM market during times of Dominion's non-coincident peak.[27]

As acknowledged by the Company, one of the primary purposes of energy efficiency measures is to reduce load.[28] In order to assess more fully the impact of the requirement of Senate Bill 966 that the Company propose $870 million in spending on new energy efficiency programs by 2028, the Company shall also model the impact of that requirement on the load forecast in all plans other than the least cost plan.[29] Specifically, this should be modeled separately as (1) an impact on the PJM peak load and energy sales forecast, and (2) a supply-side resource as currently presented. The Company should model the impact on forecasted peak load and energy sales using reasonable assumptions based on actual Virginia-specific data.

---

[25] *Id.* at 14-15; Tr. 537-542. Consumer Counsel supported this recommendation. Tr. 976.

[26] Ex. 35 (White) at 14; Tr. 880-881. The Company's original analysis using its projected load forecast remains part of this record.

[27] Tr. 880-881.

[28] Tr. 867.

[29] *See* Senate Bill 966, Enactment cl. 15.

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Solar Capacity Factor

The solar capacity factor modeled by the Company was also a significant issue in this proceeding. The record reflects that the Company's existing solar PV resources, which include both fixed tilt and solar tracking resources, have experienced lower-than-modeled capacity factors. While the Company models an approximately 26 percent capacity factor for future solar PV resources, the Company's resources have experienced actual capacity factors of approximately 20 percent on average over the past five years.[30] Several explanations for the lower-than-expected capacity factors were offered. In particular, evidence was offered that suggested wetter than normal weather, technical difficulties including outages, and differences between fixed and solar tracking technologies, which caused the actual capacity factor to be lower than the 26 percent modeled in the 2018 IRP.[31]

For purposes of the Company's corrected 2018 IRP, the Commission finds that the Company should model a 23 percent capacity factor for solar PV resources. In reaching this decision, the Commission carefully considered and weighed all of the evidence regarding the causes of the actual solar capacity factors and evidence supporting technological efficiency improvements of solar resources over time.[32]

Further in this regard, the Commission finds the Company's methodology for forecasting solar renewable energy certificate ("REC") prices to be unreasonable. The record shows that the Company's REC price methodology does not consider actual market prices of RECs, but instead

[30] *See, e.g.,* Ex. 37 (Abbott) at 7; Tr. 561-62; Ex. 38; Ex. 41.

[31] *See, e.g.,* Tr. 401-403, 567-571; Ex. 39; Ex. 48.

[32] *See, e.g.,* Ex. 37 (Abbott) at 7; Tr. 561; Ex. 38; Ex. 41; Ex. 42; Ex. 48.

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the REC price forecast is directly tied to and dependent upon the Company's forecasts of energy and capacity.[33] Specifically, the REC price forecast is the residual level necessary to make the renewable resource investment economic given the utility's forecasts of market prices for energy and capacity.[34] For purposes of the corrected 2018 IRP filing, the Company shall present an alternative methodology for forecasting REC prices that incorporates actual observable market prices for RECs.

Accordingly, IT IS SO ORDERED, and this matter IS CONTINUED.

AN ATTESTED COPY hereof shall be sent by the Clerk of the Commission to all persons on the official Service List in this matter. The Service List is available from the Clerk of the Commission, c/o Document Control Center, 1300 East Main Street, First Floor, Tyler Building, Richmond, Virginia 23219.

[33] *See, e.g.,* Ex. 35 (White) at 18-21; Ex. 43 (Scheller Rebuttal) at 14-15.

[34] *See, e.g.,* Ex. 35 (White) at 19-20; Tr. 512.

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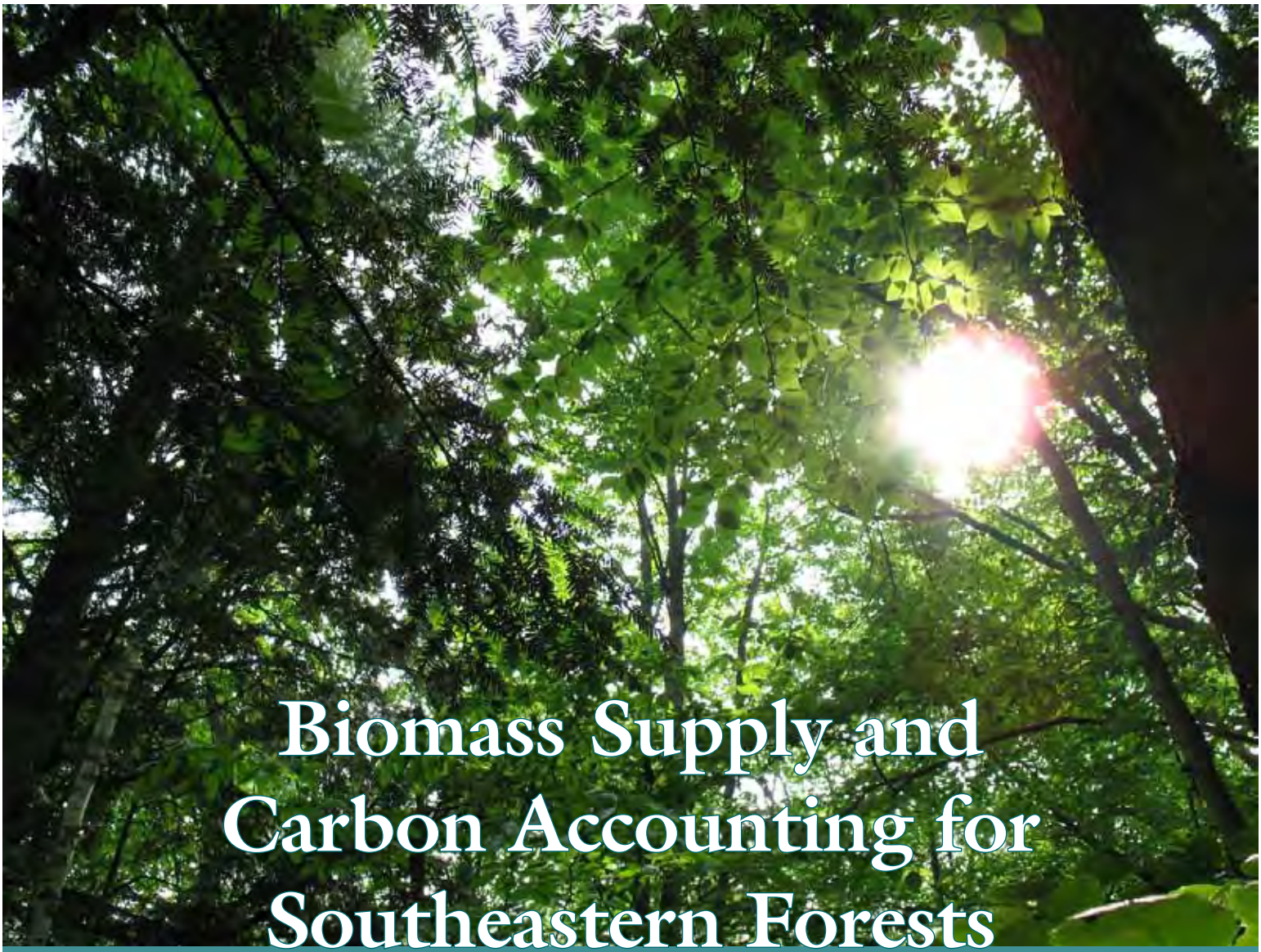
Attachment 4



Biomass Supply and Carbon Accounting for Southeastern Forests

February 2012

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This Biomass Supply and Carbon Accounting for Southeastern Forests study was conducted by the Biomass Energy Resource Center, the Forest Guild, and Spatial Informatics Group. The members of the study team included:

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The views and conclusions contained in this report are those of the authors and should not be interpreted as representing the opinions or policies of the reviewers.

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Appendix A. Technology Pathways Database
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EXECUTIVE SUMMARY

It is important to note that due to the emphasis in the Southeast on biomass electric power production, this study examines only the use of biomass for large-scale electric power generation (and electric-led combined heat and power, or CHP).

As climate change policy develops, forest biomass is consistently recognized as an alternative fuel with the potential to replace fossil fuels and mitigate the build-up of atmospheric carbon. In response to these issues, the southeastern United States has seen recent interest in significantly expanding the biomass energy sector, including building new power plants, co-firing with coal power in existing plants, pellet manufacture for export to Europe, and producing cellulosic ethanol. While some look to these developments and see promise, others look with great concern at pressures on the region's forests, implications for forest health and sustainable wood supply, and impacts on cumulative greenhouse gas emissions.

Until recently, governmental policies have almost unanimously reflected the opinion that energy from biomass is beneficial from a greenhouse gas (GHG) perspective. Biomass typically is included in energy portfolios as a renewable energy source in the same classification as wind and solar and is eligible for the same public incentives and subsidies. Starting in the early to mid 1990s, however, a number of studies looked more closely at the net GHG benefits of burning biomass and resulted in refined calculations of benefits depending on site factors, forest growth modeling, and timing of emissions and sequestration (Manomet, 2010). In the past few years, direct challenges to the accuracy of accounting approaches spurred a rethinking of carbon accounting for biomass (Searchinger, 2009).

As part of this emerging research, the US Environmental Protection Agency (EPA) is revisiting the premise that burning biomass for energy is carbon neutral in the context of the natural carbon cycle of the earth (EPA, 2011) and is considering regulating carbon emissions from biomass combustion. This study provides an example of how the "comparative" approach can be used for a specific region. It can be further evaluated by EPA to inform its criteria for an "accounting framework for biogenic CO_2 emissions from stationary sources."

KEY QUESTIONS

To address these complex issues as relevant to southeastern forests, this study seeks to address two key questions relevant to the biomass electric power sector in this region of the country:

- How much biomass (primarily wood) is available on a sustainable basis to source the expanding southeastern biomass electric power sector? And, what is the potential of public policy to create demands that exceed sustainable supply levels?
- How will the increased use of forest biomass for electric power generation in the Southeast affect atmospheric carbon over time, and how does biomass energy compare to several fossil fuel energy alternatives in terms of cumulative GHG emissions over time?

It is important to note that due to the emphasis in the Southeast on biomass electric power production, this study examines only the use of biomass for large-scale electric power generation (and electric-led combined heat and power, or CHP). Thermal energy pathways were not examined and due to their much higher efficiencies, these thermal technologies would have significantly shorter carbon payback periods and different overall impact on atmospheric carbon levels when compared to fossil fuel technologies (Manomet, 2010).

WOOD SUPPLY REVIEW

To assess the potential for sustainably harvested biomass (primarily wood) to fuel an expanded biomass energy sector in the Southeast, the study presents a literature review of several key biomass resource assessments conducted to date, examines the current and possible future energy policies that could drive the expansion of biomass energy development, and compares the supply with this potential demand. This portion of the study has three main parts:

1. assessment of the biomass resource literature for the seven-state region
2. examination of the energy policies in the seven-state region
3. comparison of the resource supply to the potential demand

The study does not present new primary fuel-supply analysis, but is based on a review of existing information. Main findings include the following points:

- Most studies conducted in the past six years quantify the gross or total amount of woody biomass material generated on an annual basis and do not quantify how much is already being used. Most of these studies focus on residues produced from other primary activities while evidence suggests nearly all the mill and urban wood residues are already used by existing markets.
- The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).
- Whether logging slash, whole trees, or pulpwood will be used in the expansion of biomass energy in the Southeast will depend on the following:
  1. Which market the wood is going to (pellet mills need high-quality fiber from pulpwood while biomass plants are less particular about quality)
  2. How much demand increases within the pellet and power market sectors over time
  3. What happens with the pulp and paper industry in the southeast region in the future
- Prior to 2009, most fuel availability studies presented estimates of supply without any acknowledgment of the influence price has on the availability of these woody biomass resources. Since then, different studies have examined the economics using different indicators—making it difficult to compare results among the studies. For a clear assessment of the economics of woody biomass resources, the total delivered price paid by the receiving facilities is the best indicator to use.
- Various studies reviewed in this chapter used widely divergent assumptions regarding what percentage of the total amount of logging residue can be recovered from a harvested area. While the range observed in the literature was from roughly 50-100 percent, it should be noted that there is a difference between how much residue *can* be recovered and how much *should* be recovered when ecological factors are taken into account. While examining how much wood fuel could be generated if 100 percent of this material was recovered is useful for academic purposes, it is unrealistic to assume that such a high level can and should be realized. Ideally, studies would look at two critical issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered.

It should be noted that there is a difference between how much [logging] residue *can* be recovered and how much *should* be recovered when ecological factors are taken into account.

EXECUTIVE SUMMARY *(cont'd)*

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood.

- The availability of logging residues will largely depend on extraction methods. Where whole-tree harvesting systems can be used, these residues can be cost effectively accessed, however, the potential ecological effects of whole-tree logging need to be considered. Where mechanized cut-to-length and manual stem-only harvesting are used, these residues will not be easily accessible. Further analysis that determines how much whole-tree harvesting systems versus stem-only harvesting systems are used across this region would be very useful.
- Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential. In contrast, Alabama and Tennessee both had very little publicly available reports estimating biomass resources.
- Evidence suggests that there is likely enough wood to meet a 15 percent federal Renewable Energy Standard (RES) applied to each of the seven states (with the exception of Florida) when woody biomass sourced from local forests accounts for no more than 20 percent of the overall renewable electric generation target (or 3 percent of electricity supplied). It also appears, however, that adequate wood fuel resources are quite sensitive to the RES allocation. For example, if 30 percent of a 15 percent RES was allocated to forest biomass, it is likely there would not be enough wood fuel available within the region. A more aggressive RES standard for biomass leads to a higher likelihood of shortages and a greater probability of pulpwood displacement.
- Capacity to access and utilize residues is also a function of how much roundwood harvest occurs. More demand for roundwood generates more residues. The extent to which biomass power plants transition their wood procurement away from residues and toward roundwood is governed by the strength of the rest of the forest products industry. If the forest products industry strengthens as a result of greater lumber demand, it will increase its wood fiber consumption and as a result, biomass power plants would procure more residues at a lower cost and less pulpwood at a higher cost. If the forest products industry as a whole continues to contract, however, biomass power plants will likely transition toward procurement of chipped fuel from whole trees assuming they can absorb the higher cost associated with that transition.

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood. Therefore, pellet mills and biomass power plants have somewhat complementary (almost symbiotic) procurement needs. Pellet production, especially the export market to Europe, will continue to play the wild card role in future wood fuel markets.

- The supply review performed as part of this study does not directly address potential ecological impacts of biomass energy sourcing. Additional analysis will be necessary to assess these impacts on other forest resources and values.
- The potential recovery rate for harvest residue is a key variable in determining the quantity of available wood fuel. Further research is needed to assess both the current achievable residue recovery rates and reasonable future recovery rates. Projected recovery rates need to consider woody biomass retention rates to meet wildlife and biodiversity, water quality, and soil productivity needs.

While this report has identified and probed some of the issues regarding the forest resource's capacity to produce more energy in the Southeast, there are numerous areas where key information is missing. More specific research is needed in the areas of: existing forest residue utilization, use of different harvesting systems, a comprehensive wood fiber assessment for the entire seven-state region, the price elasticity of demand between fuel chips and pulpwood, and the likely impacts of federal renewable energy standards on the economic incentives that drive project development.

ATMOSPHERIC CARBON ANALYSIS

To examine the atmospheric effects of biomass electric power generation in the Southeast, this study developed a new carbon accounting framework that integrates life-cycle carbon accounting with forest carbon accounting and utilizes forest growth, forest management practices, and supply data related to the specific situation in the Southeast. The framework is based on what we will call a "landscape-woodshed approach" where actual supply zones for specific facilities across the landscape are defined and aggregated as the basis for the study. Essentially, the study framework is designed to answer policy questions related to how atmospheric carbon would be affected if certain activities were promoted. It develops a "business-as-usual" baseline and then projects the atmospheric carbon effect of different future scenarios of creating electricity from woody biomass versus creating it from fossil fuels.

The framework [for this study] is based on what we will call a "landscape-woodshed approach" where actual supply zones for specific facilities across the landscape are defined and aggregated as the basis for the study.

Given the dynamics of the southeastern forestry sector, this study assumes that most of the trees modeled would eventually be harvested for pulp or other management objectives (such as to initiate the new stand under even-aged management) versus being left untouched if not harvested for biomass energy. The study excludes all public lands and 21 percent of private lands as not available for harvesting.

This is a more dynamic approach than was recommended in EPA's accounting framework for biogenic sources released in September 2011. Although, EPA acknowledged the "comparative" approach used in this study as a more comprehensive accounting method, it chose a "reference point" approach because of the perceived difficulties and challenges in applying a more dynamic approach to actual situations in the field.

EXECUTIVE SUMMARY *(cont'd)*

This study provides an example of how more dynamic accounting can be accomplished and should be considered by EPA in its carbon accounting deliberations. The results are consistent with other studies from other states or regions using similar analytical methods (Manomet, 2010 and McKechnie, 2011). Others have recently voiced opinions over which accounting methods are most appropriate. The SAF Task Force Report, Managing Forests because Carbon Matters: Integrating Energy, Products, and Land Management Policy (Malmsheimer et al., 2011), recommends a reference-point approach to establish forest biomass as carbon neutral. The European Environment Agency's Scientific Committee on Greenhouse Gas Accounting (European Environmental Agency, 2011) recently offered an opinion championing a comparative approach to fix a serious flaw in current GHG accounting.

Carbon Modeling Results

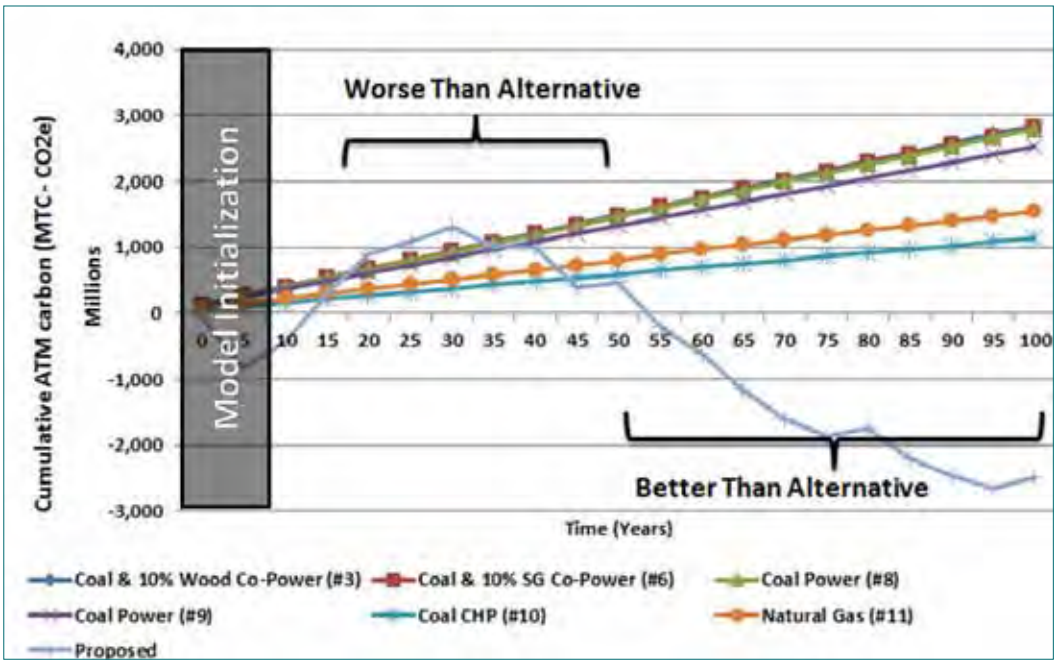
- The study modeled 22 new power plants as proposed to be developed over the next several years (1014 MW and 3.05 million tons of pellet production) added to an existing base of 17 power plants. The list of proposed plants is a snapshot compiled in May 2011 by the Southern Environmental Law Center. Additional large plants have since been proposed and are under development. As biomass demand increases with more facilities beyond the

Figure 22.

The study found that using southeastern forests for an expansion of electric power generation produced a significant long-term atmospheric benefit, but at short-term atmospheric cost.

The expanded biomass scenario creates a carbon debt that takes 35-50 years to recover before yielding ongoing carbon benefits relative to fossil fuels after this time period. (The initial apparent sequestration in the graph is a modeling artifact. It is a function of the simulation resolution and is due to the 5-year cycle with harvests mid-decade. This creates a 5-year growth period before harvest simulation.)

Figure 22. Cumulative atmospheric carbon balance over 100 years using coal and natural gas technologies to meet energy demand of proposed biomass facilities.



22 modeled, the ability of the forested landscape to provide biomass supply and store carbon may become more limited, particularly in localized areas with strong demand.

- The results indicated that the 17 existing biomass facilities were now generating and would continue to generate an improved atmospheric carbon benefit relative to fossil fuel technologies.
- The study found that using southeastern forests for the modeled expansion of power generation produced a significant long-term atmospheric benefit, but at short-term atmospheric cost. The expanded biomass scenario creates a carbon debt that takes 35-50 years to recover before yielding ongoing carbon benefits relative to fossil fuels after this time period (see Figure 22 on page 95). This outcome depends on the fossil fuel pathway used for comparison and assumes forests re-occupy the site through planting or natural regeneration, with no forest land conversion. This finding is consistent with other recent studies and naturally creates tension between climate scientists who assert that the next 20-30 years are a critical time for reducing carbon additions to the atmosphere and those who are more focused on long-term cumulative atmospheric carbon levels. This tension can only be resolved by well-informed energy and climate policy decisions.
- The efficiency of combustion technology was shown to be a critical factor influencing carbon emissions over time. The study used a mid-range value of 6,800 Bone Dry Tons (BDT) per megawatt hour per year. Using less-efficient combustion technology that requires more biomass per unit of power (e.g., using 8,000 BDT per megawatt hour per year) extends the payback period to 53 years. Using more efficient technologies would shorten this payback period. This study does not address biomass for thermal applications. While less common in the study area, strictly thermal applications or CHP applications are significantly more efficient and have much shorter carbon payback periods (in the range of 5-10 years in similar studies) than conventional combustion for base-load electrical generation that produces significant amounts of unused "waste" heat. The study also found that there is wide variability in carbon outcomes for different fuel types across different combustion systems.
- The use of logging residuals, when available from current harvests, leads to an improved carbon balance versus using standing roundwood because of the higher relative carbon storage of pulpwood versus residuals. The availability of harvest residue, however, is highly dependent on other parts of the wood products economy to generate sufficient demand for harvesting that creates residue material.
- The study did not model the use of dedicated energy crops for feedstock or crops that could be grown on fallow land and not jeopardize current sequestration and carbon stocks in existing forests. It attempted to analyze switchgrass based on information from a literature review, but this did not provide adequate or comparable information to what was available from our forest biomass modeling. Hence, a switchgrass analysis was dropped from the carbon modeling.

EXECUTIVE SUMMARY *(cont'd)*

One central issue to recognize is that [carbon] policy discussions include two competing perspectives—one long term and one short term—that will need to be assessed and weighed in the development of effective climate and energy policy.

DISCUSSION

The complex flux of forest-based carbon and the 35-50 year payback periods for the electric generation technologies modeled present both an intellectual and policy challenge. One central issue to recognize is that policy discussions include two competing perspectives—one long term and one short term—that will need to be assessed and weighed in the development of effective climate and energy policy. The long-term perspective focuses on the much lower amounts of atmopheric carbon that will eventually be realized if biomass is substituted for fossil fuels and the related beneficial effects for climate change and future generations. From this perspective, the 35-50 year payback period of biomass is less consequential. The short-term perspective, by contrast, believes near-term emission reductions are critical. This perspective is concerned with near-term "tipping points"—climate events that might be triggered by near-term increases in atmospheric carbon. From that perspective, the 35-50 year payback periods for biomass electric power are considered unacceptable climate and energy policy.

To further inform this discussion, it is useful to note that the carbon debt period shown in this study is consistent with other studies (Manomet, 2010, McKechnie, 2011) that have used life-cycle analysis, forest carbon accounting, and a business-as-usual baseline to compare biomass to other forms of energy production. As shown schematically in Figure 1 on the following page based on the Manomet study, there is an initial carbon "debt" relative to fossil fuels in the combustion of biomass for energy. Following a variable "payback" period, this debt is recovered and beyond that point biomass energy results in lower atmospheric carbon than fossil fuel alternatives.

The Manomet modeling produced a 42-year payback period for biomass- versus coal-generated electricity and the McKechnie modeling indicated 17-38 year payback periods for generating electricity with biomass instead of coal. Although these patterns are basically consistent, there are differences in debt periods, which are attributable to different forest types and harvest scenarios. In addition, our framework includes a more precise modeling of actual harvesting methods in real stands across the study region and linked to specific facilities.

Also there are significant differences between this study and the Manomet study in the time it takes to re-sequester all the emitted carbon and reach the point commonly called "carbon neutral." Our modeling indicates 53 years are required for this southeastern study region while the Manomet results for Massachusetts indicate more than 100 years are required.

Beyond the tension between this long- and short-term perspective, analyzing the climate implications of the biomass technologies modeled in this report is informed by several additional issues. First, recent climate studies indicate that whatever the ultimate peak in atmospheric carbon, it will take much longer than previously thought—hundreds or thousands of years—for the earth's systems to bring it back down to what are considered safe levels. This further complicates the understanding of how to address the short- versus long-term atmospheric carbon implications of biomass energy.

Second, it is possible to imagine future scenarios where technology leaps allow the retirement of such major sources of combustion as coal and biomass within 50 years. If realized, this would significantly shorten the payback period for biomass since facilities would be retired, biomass harvesting would stop, and re-sequestration would accelerate to shorten the payback periods. Conversely, it is possible to imagine land-use changes that would adversely affect the availability of biomass and negatively affect the payback periods. Concern over land-use change is well documented in the Southeast.

Third, it is necessary to fully consider any negative climate implications or events that could be triggered by the carbon debts created by the biomass scenarios. One should also consider whether these climate effects would eventually be triggered by continuation of the fossil fuel scenarios in the absence of biomass or other alternative fuels. Evaluating the cumulative costs and benefits to ecosystems and society of these factors over time is the task in front of policy makers in the southeastern region and at the national level.

Fourth, much of the carbon accounting debate for biomass centers on assumptions of baseline conditions. It is not uncommon to see studies that rely on generic "growth-to-removal" ratios as the key indicator of carbon accounting. The rationale is that as long as overall carbon stocks are being maintained in some specified area, then any biomass removal in that area is considered carbon neutral. This approach oversimplifies the accounting and can overlook very significant changes in forest carbon stock at the local level. They also do not accurately portray the foregone tons of new sequestration that would continue to accrue if those forests were not harvested for biomass.

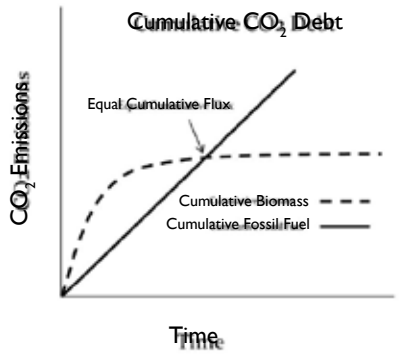


Figure 1.

Landscape-Scale Cumulative Carbon Debts and Dividends (Walker, 2012).

This study relies on a comparative approach that realistically estimates both the level of forest harvesting and the level of forest sequestration going forward in the absence of new biomass harvesting as a more accurate baseline approach. The approach used in this study can be applied to a region or an individual facility and should be useful for EPA as it develops regulations for GHG emissions.

INTRODUCTION

STUDY GOALS AND PURPOSE

Until recently, governmental policies have almost unanimously reflected the opinion that energy from biomass is beneficial from a GHG perspective.

The National Wildlife Federation (NWF) and Southern Environmental Law Center (SELC) contracted with the Biomass Energy Resource Center (BERC), in partnership with the Forest Guild and Spatial Informatics Group LLC, to provide an assessment of the greenhouse gas (GHG) impacts of an expansion of biomass electric power facilities in the southeastern United States. The study region is defined as a seven-state southeastern region including Virginia, North Carolina, South Carolina, Tennessee, Georgia, Alabama, and Florida. It is important to note that this study did not address thermal biomass energy applications, which have much higher efficiencies than electric power generation technologies and very different atmospheric carbon cycles. Nor did this study address the ecological impacts of current or increased biomass harvesting.

Energy supply and use is a national priority and a major focus of national, state, and local policy makers across the United States. The impacts of climate change, the need to increase energy efficiency, reduce reliance on foreign oil, and address related international security threats are some of the issues driving the expansion of new sources of domestic renewable energy and a new national energy policy and practice.

As climate change policy develops, forest biomass is consistently recognized as an alternative fuel with the potential to replace fossil fuels and mitigate the build up of atmospheric carbon. In response to these issues, the southeastern United States has seen recent interest in significantly expanding the biomass energy sector, including building new power plants, co-firing with coal power in existing plants, pellet manufacture for export to Europe, and cellulosic ethanol. Some of this increase in biomass utilization is driven by global demand and regulation and some by state-level renewable energy portfolios that require increased alternative energy production. To date, in the study region, North Carolina is the only state that has adopted a mandatory renewable energy portfolio standard, and Virginia has a voluntary standard. Additional state renewable portfolio standards or federal energy and climate change policies, however, will likely further increase the demand for biomass from southeast forests. According to Forisk Consulting, there are 149 announced projects in the southern United States that, in the unlikely event that they were all built, would consume more than 65 million green tons (Forisk Consulting, 2011). While some look to these developments and see promise, others look with great concern at pressures on the region's forests, implications for forest health and sustainable wood supply, and impacts on cumulative GHG emissions.

Until recently, governmental policies have almost unanimously reflected the opinion that energy from biomass is beneficial from a GHG perspective. Biomass typically is included in energy portfolios as a renewable energy source of the same classification as wind and solar and, when considered for electric power generation, is eligible for the same public incentives and subsidies. From an international perspective, policies have generally considered biomass energy to be a climate-friendly alternative to fossil fuels. In Europe for the past 10-15 years,

the International Energy Agency (IEA) has considered biomass energy to be close to carbon neutral (IEA, 2007 and 2009). The Intergovernmental Panel on Climate Change (IPCC), the primary international body focused on GHG emissions and mitigation strategies, also considers biomass energy to be an option for avoiding the GHG emissions from fossil fuels across all energy sectors (IPCC, 2000).

Starting in the early to mid 1990s, however, a number of studies looked more closely at the net GHG benefits of burning biomass and resulted in refined calculations of benefits depending on site factors, forest growth modeling, and timing of emissions and sequestration (Manomet, 2010). In the past few years, direct challenges to the accuracy of accounting approaches spurred a rethinking of carbon accounting for biomass (Searchinger, 2009).

As part of this emerging research, the US Environmental Protection Agency (EPA) is revisiting the premise that burning biomass for energy is carbon neutral in the context of the natural carbon cycle of the earth (EPA, 2011) and considering regulating carbon emissions from biomass combustion. In a 2010 rulemaking under the Clean Air Act—known as the Tailoring Rule—EPA planned to (and for a short while did) regulate carbon emissions from biomass plants as it did carbon emissions from fossil fuel burning facilities. EPA, however, also committed to studying the "carbon-neutrality" issue to determine whether the federal statute allowed carbon emissions from biomass combustion to be regulated differently than carbon emissions from the burning of fossil fuels. After extensive public and industry feedback on these new carbon emission rules as applied to biomass facilities, EPA proposed in March 2011 and finalized in July 2011 a different approach under which it instituted a three-year deferment of the regulation of biomass energy CO_2 emissions while it studied the underlying issue. During the study period, EPA said it would seek the advice of federal partners, states, a diverse group of expert scientists, and an independent scientific panel to help determine how these emissions should be treated under its air permitting program (EPA, 2011).

In September 2011, EPA released an "Accounting Framework for Biogenic CO_2 Emissions From Stationary Sources" to begin the discussion with experts and the public (EPA, 2011). EPA acknowledges several baselines that could be used in its framework, including the one used in this study, but selects a "reference-point" baseline that looks at the net change in carbon from a current reference point. Thus, if a region's stock of biomass contained more carbon after a specific point in time than the present, it would be assumed that biomass usage was not affecting atmospheric carbon. This southeastern study, by contrast, uses what EPA calls a "comparative" approach that identifies the net change that will occur in an alternative future, that is, how the carbon balance will be different if we use biomass as a source of energy versus using fossil fuels to produce that same amount of energy. The EPA framework also recognizes the carbon debt that could be incurred by land-use changes, but quantifies these emissions at a landscape scale and analyzes them on an annual basis. This southeastern study does not consider large-scale land-use change, but rather considers increased use of biomass energy harvested from forests on a sustainable basis. As this study points out, additional information is needed to determine how much additional forest biomass is available across the seven-state region to sustainably supply an expanded biomass energy sector without resulting in large-

Starting in the early to mid 1990s, however, a number of studies looked more closely at the net GHG benefits of burning biomass and resulted in refined calculations of benefits depending on site factors, forest growth modeling, and timing of emissions and sequestration.

INTRODUCTION *(cont'd)*

Overall, this literature review presents an overview of what is known about how much biomass resource is available in the region, what additional information is needed, and how closely matched current energy policy is with these available resources.

scale land-use change with related carbon and ecological effects. EPA's reasoning for selecting a less dynamic approach was the difficulty and challenges in accounting for these variables in actual situations. Others have recently voiced opinions over which accounting methods are most appropriate. The SAF Task Force report, Managing Forests because Carbon Matters: Integrating Energy, Products, and Land-Management Policy (Malmsheimer et al., 2011), recommends a reference-point approach to establish forest biomass as carbon neutral. The European Environment Agency's Scientific Committee on Greenhouse Gas Accounting (European Environment Agency, 2011) recently offered an opinion championing a comparative approach to fix a serious flaw in current GHG accounting.

This study provides an example of how the "comparative" approach can be used for a specific region. It can be further evaluated by EPA to inform its criteria for an "accounting framework for biogenic CO_2 emissions from stationary sources."

To address these complex issues as relevant to southeastern forests, this study seeks to address two key questions relevant to the biomass electric power sector in this region of the country:

1. How much biomass (primarily wood) is available on a sustainable basis to source the expanding southeastern biomass electric power sector, and, what is the potential of public policy to create demands that exceed sustainable supply levels?
2. How will the increased use of forest biomass for electric power generation in the Southeast effect atmospheric carbon over time and how does biomass energy compare to several fossil fuel energy alternatives in terms of cumulative GHG emissions over time?

It is important to note that this study examines only the use of biomass for large-scale electric power generation (and electric-led combined heat and power, or CHP). Thermal energy pathways were not examined, and due to their much higher efficiencies, these thermal technologies would have significantly shorter carbon payback periods and different overall impact on atmospheric carbon levels when compared to fossil fuel technologies (Manomet, 2010). It is also important to note that this study focuses solely on the carbon accounting of increased biomass use. There are significant ecological effects of increased removals of biomass from southeastern forests that must be evaluated and accounted for and were not within the scope of this study.

To examine fuel supply, the study conducts a literature review and critique of relevant and publicly available studies pertaining to the supply of biomass materials (primarily wood) in the seven-state region. It also examines current and future energy policies that could drive the expansion of biomass energy development and compares regional biomass supply with this potential demand. Overall, this literature review presents an overview of what is known about how much biomass resource is available in the region, what additional information is needed, and how closely matched current energy policy is with these available resources.

To examine the atmospheric effects of biomass electric power generation in the Southeast, the study develops a new carbon accounting framework that integrates life-cycle carbon accounting with forest carbon accounting and utilizes forest growth, harvest, and supply data related to the specific situation in the Southeast. The framework investigates specific landscape woodsheds associated with biomass facilities and develops business as usual baselines to compare to alternative future energy scenarios. This framework is designed to answer the following three questions:

1. What are the atmospheric carbon implications of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?
2. What are the atmospheric carbon implications of operating the existing 17 biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants? Answering this question includes a range of sensitivity analyses, including the impacts of varying the proportions of residuals versus pulpwood and natural forests versus plantations.
3. How does the atmospheric carbon balance vary when key parameters of the model are changed? The model and additional research were used to examine the sensitivity of six parameters to atmospheric carbon balance.

A NEW CARBON ACCOUNTING FRAMEWORK TAILORED TO SOUTHEAST FORESTS AND BIOMASS ENERGY

Comprehensive and specific accounting approaches are required to measure the effect of forest biomass energy systems on atmospheric carbon. Biomass systems are scientifically complex and their atmospheric carbon effects vary over time. Yet what makes them complex is also what can make them desirable for climate change mitigation—they are based on biogenic systems. A biogenic system such as a forest is part of the natural biological cycles of the planet. The carbon in a forest fluxes in and out of the atmosphere as trees grow and accumulate carbon and then die and release it. Fossil fuels, in comparison, are part of a geologic system. These fuels were stored in the earth millions of years ago and when extracted and burned for energy release additive carbon into the biogenic cycle. While the actual carbon molecules are identical, this additional carbon loading exceeds the sequestration capacity of existing forests and oceans. The resulting net increase in atmospheric carbon causes global warming and climate change.

Comprehensive and specific accounting approaches are required to measure the effect of forest biomass energy systems on atmospheric carbon.

The analysis of the atmospheric carbon impacts of biomass energy use would be straightforward and lead to the conclusion that biomass is preferable to fossil fuels in respect to reduction of GHG emissions except for three important facts. First, in most cases, the initial release of carbon into the atmosphere from burning biomass is higher than that of fossil fuels, as biomass is less energy dense than fossil fuels. This means that more biomass must be burned and more carbon released to get the same output of heat or electricity.

INTRODUCTION *(cont'd)*

Determining how biomass can contribute to a sound climate change policy hinges upon understanding this cycle of short-term costs and long-term benefits and weighing these costs and benefits relative to mitigating climate change over time.

Second, it takes time to re-sequester the carbon released from biomass combustion and to recover the foregone sequestration capacity lost when the biomass is harvested. Forests will respond differently to biomass harvests and this can result in varying and significant periods of time it takes to re-sequester the carbon. Depending on how the fuel is harvested and burned, CO_2 emissions from biomass can be re-sequestered in forests quickly or it may take many decades. Critical factors that influence the cumulative atmospheric carbon effects of burning biomass for energy include forest type, forest management, and how harvesting is distributed across the landscape and over time.

Third, the amount of CO_2 released per unit of energy produced varies significantly across different combustion technologies, with high-efficiency thermal technologies releasing far less carbon per unit of energy than electric power generation (Manomet, 2010). This is because much more usable energy value is available—as much as 70-80 percent in thermal applications—as compared to conventional combustion technologies.

Determining how biomass can contribute to a sound climate change policy hinges upon understanding this cycle of short-term costs and long-term benefits and weighing these costs and benefits relative to mitigating climate change over time. Specifically, effective energy and climate policy must consider both short-term carbon emissions and long-term atmospheric carbon accumulation and relate these factors to actual climate change tipping points and long-term mitigation goals.

These equations are complex and there is danger in blanket approaches or oversimplifications concerning the full life-cycle carbon effects of biomass energy. Research demonstrates that not all biomass energy can or should be considered a priori "carbon neutral." It is important to have a complete understanding of the three factors described above.

These concerns have led to refinements in biomass accounting protocols that now integrate life-cycle assessments and forest carbon accounting to produce a comprehensive picture of total GHG emissions over time. This study for the Southeast integrates these new accounting protocols with a "comparative" approach and a business-as-usual baseline to depict GHG emissions as a "debt-and-dividend" model as pioneered in a 2010 study, Biomass Sustainability and Carbon Policy, conducted for the Massachusetts Department of Energy Resources (Manomet, 2011). This report for Massachusetts described the flux of carbon at the forest-stand level when biomass is burned versus a fossil fuel as resulting in an initial period when biomass released more carbon into the atmosphere than an equivalent amount of fossil fuels. This difference (or "debt") gradually decreased as the harvested forest grew and sequestered carbon. If sufficient carbon is re-sequestered, the amount of carbon in the atmosphere becomes less than the fossil fuel alternative and dividends, or benefits, are accumulated over time. The study then used individual stand data to predict the results of running biomass facilities year after year, modeling carbon released into the atmosphere each year as more forest stands are harvested to supply biomass facilities.

Each year the cumulative amount of carbon in the atmosphere increased and was offset by the sequestration that occurred in the stands that were harvested and continue to grow. The cumulative debt rises until there is enough growth on the harvested stands already in the system to balance out the re-occurring debt from the yearly harvest and biomass emissions. At this point, the cumulative emissions for biomass stabilizes around an amount of carbon that, on average, has been permanently removed from the forest and will remain in the atmosphere as long as the biomass facilities are running and harvests continue. This curve can be plotted against the cumulative emissions from fossil fuel energy sources and technologies to provide a carbon flux analysis helpful for policy considerations.

The "debt/dividend" ratio and payback period will vary significantly across technology types and fossil fuel options with the shortest payback periods for biomass thermal energy and the longest for biomass electric power (Manomet, 2010). The most notable finding in the Massachusetts study was that biomass used to produce heat or heat-led CHP took only about 5-10 years to realize atmospheric carbon benefits relative to oil while biomass used to make electricity took approximately 42 years to achieve an atmospheric carbon benefit relative to coal. This is due to the significant difference in combustion efficiency between electrical-led versus thermal-led technologies.

The Manomet study was limited in scope due to available resources and time frame and reflected some peculiarities of a forestry sector that has few parallels in other states or regions, such as a lack of pulpwood markets for low-quality material, a reluctance of many landowners to conduct the sawtimber harvests that produce residues, and harvesting regimes that do not rely on clear cutting to establish new regeneration. Also, it modeled individual stands and averaged these to represent a broader landscape versus actually modeling multiple stands across a real landscape. For these reasons, there have been lingering questions as to whether the carbon flux profile would hold up under more comprehensive modeling in different regions and forest types and utilizing more accurate harvesting regimes.

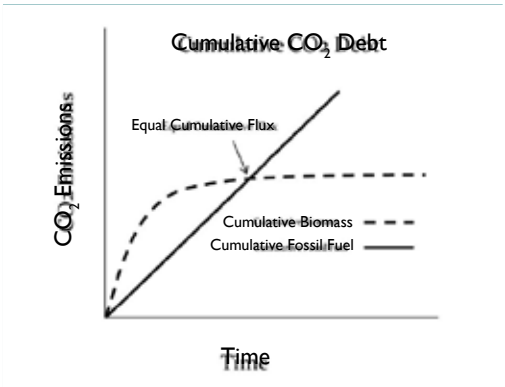


Figure 1.

Landscape-Scale Cumulative Carbon Debts and Dividends (Walker, 2012).

A related study in 2010 (McKechnie) also used an integrated approach of life-cycle analysis and forest carbon to analyze the effect of different biomass pathways compared to fossil fuels for forests in Ontario, Canada. It confirmed both the basic flux profile and significant payback periods for biomass electric power and cellulosic ethanol that were found in the Manomet study. Electrical generation using pellets in place of coal showed payback delays of 16-38 years and more than 100 years for ethanol produced from standing trees.

Enhanced modeling in this study allows a more accurate representation of GHG emissions over time and is specific to an actual forested landscape that is currently supporting 17 facilities and the expanded landscape that could be called upon to supply 22 proposed biomass facilities. The study uses life-cycle analysis and forest carbon modeling of actual forest stands across the landscape to produce a business-as-usual baseline and

INTRODUCTION *(cont'd)*

[This study] utilizes a dynamic model by predicting the role of repeated future harvests across the southeastern sourcing area for specific plants or "landscape woodsheds" as part of a business-as-usual scenario.

permit a comparison of generating energy from biomass to other ways of producing energy. The data is presented in a debt-and-benefit pattern to represent the carbon flux over time and facilitate policy development.

To further clarify several important characteristics of this study, the following issues are emphasized to facilitate comparisons to related work:

1. The GHG accounting framework used in this report represents a fresh and more realistic approach to estimate the landscape-level impacts of biomass energy expansion. In general, there are three ways to approach the modeling of GHG impacts of biomass energy:
   - Consider a *fixed landscape* and measure overall carbon stocks as an indicator of "biomass carbon neutrality" (EPA, 2011)
   - Conduct analysis at a *stand level*, multiplied upwards to estimate the landscape effect (Manomet, 2010)
   - *Consider a dynamic landscape and focus on "landscape woodsheds" to analyze the difference between emissions from the business-as-usual scenario and net changes in emissions from the increased use of biomass across different feedstock and technology pathways*

Unlike other studies that rely on variations of the first two approaches, this report uses the third method (in italics above). That is, it utilizes a dynamic model by predicting the role of repeated future harvests across the southeastern sourcing area for specific plants or "landscape woodsheds" as part of a business-as-usual scenario. It is important to note that with respect to biomass energy, the term 'landscape' approach has come to mean several different things: most often a static balance-sheet approach to carbon stocks rather than the dynamic model used here.

2. Given the dynamics of the southeastern forestry sector, this study assumes that most of the trees modeled would eventually be harvested for pulp or other management objectives (such as to initiate the new stand under even-aged management) versus being left untouched if not harvested for biomass energy. The study excludes all public lands and 21 percent of private lands as not available for harvesting.
3. This study analyzes the harvest and carbon flows for specific woodsheds and biomass facilities. It predicts and models the harvest area and harvests from the specific forest types that would feed the biomass facilities.
4. This study includes a sensitivity analysis to evaluate several variables that can be manipulated through public policy to generate different carbon payback periods. These include:
   - **Mill residuals and urban tree waste.** Biomass power plants can use sawmill waste and urban tree waste as fuel (versus in-forest residues or pulpwood). How does the carbon payback change with varying proportions of this source of woody biomass versus in-forest residuals?
   - **In-forest residues versus main stem (pulpwood).** Biomass power plants can use in-forest residues (tops and limbs) or the main stems of standing trees. How does the carbon payback change as varying percentages of residues versus main stems are used for fuel?

- **Percentage of available residue allowed in harvest.** For ecological reasons, it may be necessary to limit the total amount of residues removed from the forest. How does the carbon payback change if residue harvest is limited by management guidelines?
- **Plantations versus natural forest stands.** Forest plantations are planted and manipulated much more intensively than natural stands and often have faster growth rates. The productivity of plantations versus natural stands was considered on a stand-level basis. Since the model used real sourcing areas for existing and proposed plants, however, it was not possible to adjust the supply upward for plantations when not enough plantation supply was available. Therefore, it was not possible to study the actual change in carbon payback periods for biomass sourced from plantations versus natural stands for the study region.
- **Efficiency of biomass combustion.** The efficiency of conversion of woody biomass to energy has a significant impact on the carbon payback period for electric power production. How does varying the amount of biomass needed to produce a MW of power change the carbon payback period?
- **Pellet export percentage.** Wood pellets are manufactured in the Southeast and are used domestically or exported to Europe to produce electric power. The study examines whether varying the level of pellet export significantly changes the carbon payback period.

The study presented here seeks to address these complex issues for the forest types, energy demands, harvesting regimes, and public policy environment specific to the defined seven-state forested region of the southeastern United States.

1. WOOD SUPPLY REVIEW

1.1.0 INTRODUCTION

This literature review is focused on woody biomass resources and does not include other biomass materials such as farm manures, bio-solids, or agricultural residues.

Over the past few years, there has been a flurry of biomass energy development activities in the southeastern United States—everything from announced cellulosic ethanol plants, to pellet mills exporting product to Europe, to new power plants and retrofitting coal power plants to co-fire using biomass fuel. While the promise of cellulosic ethanol commercialization and deployment has not yet come true, there is considerable progress underway in the pellet and power production fronts. A recent announcement released by a private consulting firm that tracks biomass energy development in the United States states that there are 81 proposed electric generation projects, 51 pellet plants, and 17 liquid-fuel production plants in the southern United States with a combined biomass feedstock demand of 65 million tons (Forisk Consulting, 2011). According to the same report, however, roughly half of these projects are deemed immediately unviable by the consultant for various reasons (unproven technology, financing, permitting, wood contracts, etc.). How many of the remaining projects will eventually get built is extremely difficult to predict.

At the same time, there have been dozens of different studies quantifying the various biomass resources. Some examine resources at the national level while others hone in on the regional and state levels. Many studies examine all biomass materials from bio-solids from waste-water treatment plants to animal manures from farms. Other studies focus exclusively on woody biomass. Some are public while others are conducted by consultants for private clients and are not publicly accessible. Some use transparent data, methods, and assumptions while others are more opaque. Some focus on quantifying the total generation of biomass materials while others try to identify the net amount available after all current demands are accounted for.

Considerable information is available at the state level about the supply of biomass resources, however, biomass materials like wood tend to constantly flow across state borders to feed the markets and are not confined to use by in-state markets. For this reason looking at the regional supply and potential demand for the resource is needed.

This chapter presents a literature review of several key biomass resource assessments conducted to date, examines the current and possible future energy policies that could drive the expansion of biomass energy development, and compares the supply with this potential demand.

1.2.0 SCOPE OF STUDY AND METHODS

1.2.1 Scope of Study

The scope of this section of the study has three main parts:

1. **Assessment of the biomass resource literature for the seven-state region.** This literature review is focused on woody biomass resources and does not include other biomass materials such as farm manures, bio-solids, or agricultural residues. It covers the studies and data that are publicly available and does not address the possibly vast amount of information that is not in the public domain.

More specifically, this assessment examined resource assessment studies that addressed the supply of urban wood residues (wood pallets, tree trimmings, leftover Christmas trees, etc.), wood residues from primary wood manufacturing (sawdust, chips, and bark from sawmills), wood residues for secondary wood manufacturing (scrap wood pieces, sawdust, and wood flour from furniture, cabinet, and flooring manufactures), logging residues from the harvest of traditional timber products (primarily the top and limb wood), wood residues thinned from pre-commercial harvests, and the possible harvest of pulpwood.[1]

2. **Examination of the energy policies in the seven-state region.** This examination includes the assessment of existing state Renewable Energy Portfolio Standards (RPS), the potential for a federal Renewable Fuel Standard (RFS), and a possible future federal Renewable Portfolio Standard.
3. **Comparison of the resource supply against the potential demand.** This comparison factors the woody biomass resource, the potential pellet export market, and the possibility for dedicated energy crops to bridge a potential gap between supply and demand.

Figure 2.

Seven-state study region in the southeastern United States.

1. WOOD SUPPLY REVIEW *(cont'd)*

This literature review limited the scope to those studies published since 2005 and that squarely addressed the quantity of biomass supply within at least a portion of the seven-state region.

1.2.2 Methods

For the literature review, all biomass studies in the seven-state region were gathered, this information was reviewed and assessed, the various pieces of information were woven together to paint a more comprehensive picture, and our findings and observations were reported.

The information gathered via the literature review was incomplete and further work to assess the full picture was necessary. BERC gathered more state-specific data from the USDA Forest Service's Forest Inventory Analysis (FIA) Program, and made basic calculations to better assess the forest resource potential against the possible future demands stemming from federal energy policies.

For the assessment of the RPS for the seven-state region, the study conducted the following tasks:

1. Review the seven-states' current energy policies, identify states with an existing RPS standard, and determine whether any such standards contain a "carve out" specifically calling for a percentage of the total portfolio to come from biomass, and more specifically, woody biomass.
2. Determine the current electrical demand profile in each of the seven states.
3. Explore new possible demand scenarios if a federal RPS and RFS were implemented.
4. Compare these scenarios against the resource amounts identified in the literature review.

1.3.0 ANNOTATED BIBLIOGRAPHY

The target of this literature review was on studies that quantify the amount of biomass resource potentially available to supply future growth of biomass energy in the seven-state region. It should be noted that there are dozens and dozens of studies published in the past 10 years that touch upon the issue of biomass fuel supply. Many of these studies, however, focus on different geographic regions, on different biomass resources, on the various ecological impacts, or on the economics of biomass fuel supply. This literature review limited the scope to those studies published since 2005 and that squarely addressed the quantity of biomass supply within at least a portion of the seven-state region. Studies that did not meet these criteria were excluded from the following summary.[2]

1.3.1 National Studies

1.3.1.1 The Billion-Ton Study

In 2005, a joint report between the US Department of Energy and the US Department of Agriculture was released that quantified the amount of biomass resources potentially available to expand the use of biomass energy in the United States (Perlack, 2005). This report, commonly referred to as the "Billion-Ton Study" provided national estimates of wood residues from timber and lumber production, crop residues, fuel wood thinned from forests to reduce fire hazards, and the role of dedicated energy crops. The report concluded that there was more than 368 million dry tons per year of woody biomass from the nation's forests and another 998 million dry tons of resources from agriculture. These estimates of supply are for total generation of supply

and do not account for current demands for this resource. These estimates also include key assumptions about implementing new practices in forestry and agriculture that will generate additional volumes not currently available (such as increasing forest thinning for fire-hazard reduction and planting of dedicated energy crops).

This study's major shortcomings were that it did not make any clear effort to delineate the amount of existing demand for these materials from existing industries. The reporting was given in totals for the nation and did not provide a state-by-state breakdown of the supply in the body of the report or appendices, and therefore cannot help directly in determining the likely supply for the seven-state region being examined as part of this report. Lastly, much of the data and methods used were not made transparent, therefore making it difficult to gauge the credibility of the information being reported.

In an effort to address many of the key shortcomings of the 2005 study, the authors have recently released a detailed update that has improved the spatial resolution of the information (county level data reported for all 50 states), provided price curves for the supply of various biomass resources (indicating the supply elasticity of the various biomass resources at different price points), improved upon the data and methods used, and provided more sophisticated modeling (including land-use change) to assess future supply under different scenarios. In August 2011, the updated Billion-Ton Study was released by the lead researchers at Oak Ridge National Laboratories.

The Billion-Ton 2011 Update assumed a logging-residues recovery rate of 70 percent, leaving the remaining 30 percent onsite. Perhaps one of the most relevant conclusions emerging from the 2011 update was the following statement:

"Over the estimated price range, quantities vary from about 33 million to 119 million dry tons currently to about 35 million to 129 million dry tons in 2030. Primary forest biomass (i.e., logging and fuel treatment operations and land clearing) is the single largest source of feedstock. The resource potential does not increase much over time given the standing inventory nature of the resource and how it is managed. Results also show that very little conventional pulpwood is available for bio-energy at prices below (about) $60 per dry ton." (Perlack, 2011)

These projections of wood biomass resources represent a very large decrease compared to the estimates given in the 2005 study (from 368 down to 129 million dry tons). The reasons for this decline given by the authors are the subtraction of biomass resources already in use and the recent decline in pulpwood and sawlog markets.

1.3.1.2 A Geographic Perspective on the Current Biomass Resource Availability in the United States

In December 2005, the National Renewable Energy Laboratory issued a report by lead author A. Milbrandt entitled, A Geographic Perspective on the Current Biomass Resource Availability in the United States. Unlike the 2005 Billion-Ton Study, Milbrandt provided state-by-state estimates for crop residues, wood residues, urban wastes, methane from manure and landfills, and dedicated energy crops. Milbrandt also provided detailed information on the data and methods used to create the estimates given in the report. To estimate the amount of mill residues and forest residues, the author used 2002 data from the FIA program's Timber Products Output (TPO) for logging residues from commercial harvest and pre-commercial thinning. Table 1 on the next page presents the estimates for forest residues presented in this report.

1. WOOD SUPPLY REVIEW *(cont'd)*

Table 1. Estimates for Forest Residues

STATE	DRY TONS OF FOREST RESIDUE FROM HARVESTING
Virginia	2,403,000
North Carolina	2,995,000
South Carolina	1,733,000
Georgia	3,556,000
Florida	1,778,000
Alabama	2,555,000
Tennessee	1,319,000
TOTAL	**16,339,000**

(Milbrandt, 2005)

These estimates are based on survey data on how much wood is harvested annually and calculations based on volume ratios between the amount of traditionally merchantable roundwood harvested and the amount of tops and limbs severed and left behind. With these types of estimates, it is important to note that the methodology used does not distinguish between the total amount generated and the amount that currently goes unused by existing markets. For this study, the estimates represent the total generated. It is also important to note that not all of this residue generated could be cost-effectively gathered. In practice, only whole-tree harvesting methods allow for cost-effective collection of the top and limb wood generally left behind with either manual or mechanized stem-only harvesting. Without good data on how much whole-tree versus stem-only harvesting occurs in the Southeast (or methods to predict changes in the ratio into the future), it is difficult to accurately estimate how much of this material is/will be truly available.

1.3.1.3 Availability and Sustainability of Wood Resources for Energy Generation in the United States

In this study commissioned by the American Forest & Paper Association, the authors focused on assessing the quantity of "wood resources for energy generation that exist independently of and in excess of those needed to manufacture other forest products and can be harvested without jeopardizing the long-term sustainability of US forests" (Mendell, 2010).

This study concluded that while there was a considerable decline in wood consumed by the forest products industry between 2005 and 2010, that by 2020 the industry would recover to previous levels of timber demand. The authors concluded, however, that the pulp and paper industry's consumption of raw wood would "remain flat and decrease."

This study built upon the Billion-Ton Study and made a good effort to isolate the portion of the total supply that is "readily available." While the original Billion-Ton Study concluded there is 368 million dry tons of woody biomass (revised to 129 million in 2011) from our forests available, this study concluded there are only 50 million dry tons (roughly 100 million green tons) readily available for energy use in the United States.

This study did not provide a state-by-state breakdown of the supply in the body of the report or appendices, and therefore cannot help directly in determining the likely supply for the seven-state region being examined as part of this report.

1.3.2 Regional Studies

1.3.2.1 Eastern Hardwood Forest Region Woody Biomass Energy Opportunity

In October 2007, the US Forest Service released a study entitled, Eastern Hardwood Forest Region Woody Biomass Opportunity. Prepared by Summit Ridge Investments, it focused on the market opportunities for utilizing woody biomass within a large eastern region (nearly every state east of the Rocky Mountains). It conducted some assessment of the resource building upon work conducted in the Billion-Ton Study and concluded that at the national level, of the 368 million dry tons annually, there are only 279 million dry tons available under current practices and activities. The additional 89 million dry tons would require new practices. It also concluded that within the Eastern Hardwood Region of the United States, there are approximately 190 million dry tons annually, however, 120 million dry tons are already used for existing markets.

According to the author, the remaining 70 million dry tons available to supply additional biomass energy market expansion would represent a 50-percent increase over the current levels of wood consumption (Millard, 2007).

This study did not provide a state-by-state breakdown of the supply in the body of the report or appendices and therefore cannot help directly in determining the likely supply for the seven-state region being examined as part of this report.

1.3.2.2 Estimates of Biomass in Logging Residue and Standing Residual Inventory Following Tree-Harvest Activity on Timberland Acres in the Southern Region

The USDA Forest Service's Southern Research Station released in January, 2011 a report entitled, Estimates of Biomass in Logging Residue and Standing Residual Inventory Following Tree-harvest Activity on Timberland Acres in the Southern Region. The authors, Conner and Johnson, examined the amount of logging residues left by current harvesting and the standing trees left behind by harvesting that could be used for energy in a 13-state region of the southern United States. The authors examined all harvesting in the study area over the past 14 years and broke the harvesting into several categories—final harvest, commercial thinning, partial harvest, seed-tree/shelterwood, and Timber Stand Improvement (TSI). This study concluded there is the potential to recover an estimated 62.9 million green tons of harvest residues in their 13-state region annually.

Table 2 on the following page presents key information extracted from the Conner and Johnson study for the seven-state study region.

1. WOOD SUPPLY REVIEW *(cont'd)*

Table 2. Key Information Extracted from the Conner and Johnson Study for the Seven-State Region

	Final Harvest (Acres Harvested Annually)	Commercial Thinning (Acres Harvested Annually)	Partial Harvest (Acres Harvested Annually)	Shelter-wood (Acres Harvested Annually)	Timber Stand Improvement (Acres Harvested Annually)	Total (Acres Harvested Annually)	Logging Residue (Resulting Green Tons)
Virginia	133,600	55,100	117,900	2,600	10,400	319,600	4,863,222
North Carolina	227,500	101,800	87,100	2,100	10,600	429,200	5,936,953
South Carolina	149,800	200,000	63,900	13,200	13,000	439,800	4,773,409
Georgia	296,100	316,600	129,300	16,200	18,000	776,200	7,512,195
Florida	190,600	61,900	69,100	3,300	5,500	330,500	2,850,164
Alabama	366,400	275,200	164,600	14,900	15,600	836,700	7,951,820
Tennessee	56,600	4,400	161,500	3,900	1,200	227,600	2,905,345
TOTAL	**1,420,000**	**1,015,000**	**793,400**	**56,200**	**74,300**	**3,359,600**	**36,793,108**

Table 2 indicates that, according to the data and methods used by Conner and Johnson, there are more than 36 million green tons (or 18 million dry tons) of logging residues that could be used in the seven-state region, representing an average of 11.15 green tons per harvested acre. It is important to note that the authors chose to discount to the total amount of harvest residues calculated to account for a realistic recovery rate, using a 60 percent recovery rate for logging residues. It is unclear if this recovery rate is intended to be applied to all harvest operations where only 60 percent of the residue is gathered—factoring logistical and ecological reasons for not recovering more—or if this recovery rate applies to taking all residues from only 60 percent of the harvest operations. This is an important point because ideally, a study would look at both issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered. In addition, the extent to which these harvest residues can be cost-effectively harvested depends largely on the type of harvesting system used by the loggers: Whole-tree harvesting can cost effectively extract this material whereas stem-only harvesting systems leave these materials scattered in the woods. To better understand how much top and limb wood residues from harvesting could effectively be accessed in the seven-state region, good information about how much whole-tree harvesting versus stem-only harvesting is needed. Unfortunately, other than general anecdotal information from loggers and foresters, this information was not found.

1.3.2.3 An Interactive Assessment of Biomass Demand and Availability in the Southeastern United States

In March of 2011, The Environmental Defense Fund and the Nicholas Institute for Environmental Policy Solutions at Duke University released a model and paper entitled, An Interactive Assessment of Biomass Demand and Availability in the Southeastern United States. The paper's authors, Galik and Abt, detailed the function and general results of the modeling work.

The model currently only holds data for three southeastern states—Georgia, South Carolina, and North Carolina. The model does not specifically quantify the amount of woody biomass potentially available, but rather explores the potential impact on the forest resource of hypothetical demand scenarios stemming from the adoption of a federal RES or a federal RFS. The model utilizes previous Sub Regional Timber Supply (SRTS) modeling work and feeds these data into an Excel spreadsheet where the impacts of various demand scenarios are compared to the biomass resource under different levels of resource constraints. The framework of the model explores a wide range of percentages of biomass contribution (or biomass "carve outs") toward a possible RES (1-10 percent) or RFS (0-150 percent).

On the whole, the modeling effort indicated that it was possible to meet the resource demands of all the different policy scenarios explored when whole-trees were an allowed resource. When the model parameters were confined to only harvest residues (tops and limbs left from traditional timber harvesting), however, there was insufficient resource to meet the energy policy targets of most scenarios for the three states.

One rather interesting observation the authors made concerned the potential for the displacement of traditional pulpwood by the increased demand and price paid by emerging biomass power generation markets. The authors suggested that "where the price of biomass increases, some existing users may essentially be priced out of the market," meaning those markets that are the most price sensitive with the least capability to pass along higher raw wood costs through the supply chain will have a harder time getting the resource. Galik and Abt state "we assume that the electric sector are not price sensitive... [and] as biomass prices increase, [existing forest products industry] are the first to be priced out" (Galik, 2011).

It is important to note that these assumptions are just that—assumptions. If a federal RES were implemented without set targets for biomass, solar, and wind, and biomass proved to be the most cost effective, then there is a chance demand for biomass could drive wood prices up to a point where biomass could outcompete pulpwood. There is little evidence, however, that such a reaction would take place. In fact, there is considerable evidence of the opposite. First, all RES implemented to date contain an alternative compliance payment that sets a cap on how high renewable energy credit prices can go. Second, the electric plants using biomass have historically been the most price-sensitive and constrained portion of the wood market (operating at 25 percent efficiency tends to limit how much they can afford to pay for wood fuel). Furthermore, the pulp and paper industry is not likely as price constrained as Galik and Abt suggest. The current market price paid for delivered fuel chips by power plants in the Southeast ranges between $22-$26 per green ton whereas the current price paid for delivered residual chips at pulpmills in the Southeast ranges from $32-$38 per green ton (North American Fiber Review, June 2011).[3]

1. WOOD SUPPLY REVIEW *(cont'd)*

Pulpmills also demand significantly higher quality chips that cost more to produce than the typical woodchip fuel used by power plants. In addition, the market value of the processed pulp is more than $500 per ton and the price of bulk paper is nearly $1,000 per ton. Even with an aggressive RES creating a strong incentive for biomass energy, it would be difficult to set a high-enough rate per MWh to price out pulp for the source wood while still making biomass energy even remotely price competitive with other sources of electric generation.

In certain circumstances, pulpwood can be sent to power plants—if a biomass power plant is very close to the harvest location and the nearest pulpmill is far away, pulpwood would likely be sent to the biomass plant as demand and prices rise for biomass fuel. If a harvest operation occurs 50 miles from the nearest biomass plant and 50 miles from the nearest pulpmill, however, under today's market prices the pulpwood will clearly go to the pulpmill.

1.3.2.4 Using Southern Interface Fuels for Bioenergy

In January 2011, the USDA Forest Service's Southern Research Station released a study examining the potential to use woody biomass sourced from within the Wildland Urban Interface (WUI) for biomass energy development. This study specifically examined the amount of wood residues from timber harvesting, unmerchantable wood from pre-commercial thinnings of timber stands, urban wood recycling, and exotic plant removals. It covers a 13-state region of the southern United States but did not present any new work regarding the amounts of woody biomass potentially available (Staudhammer, 2011).

1.3.3 State Studies

Due to the fact that the national and regional supply studies reviewed here thus far present little information specific to the seven-state region in question, our review now shifts its emphasis on gathering as much pertinent information on biomass supply in each state in an effort to compile these data for the whole seven-state area.

1.3.3.1 Virginia

Parhizkar and Smith (2008) conducted an assessment of wood residues in Virginia using GIS-based spatial analysis. Their analysis focused on the woody biomass residue generation from loggers, sawmills, secondary wood manufacturers, and landfills. The authors surveyed these sources and compiled the resulting data in a GIS application. They concluded that there is 8.1 million tons annually generated by wood products manufacturers in Virginia, but more than 90 percent of this material has existing markets. The assessment estimated that there was roughly 770,000 green tons of logging residues generated in 2003 and another 1.2 million green tons is disposed and sometimes diverted at landfills. Only eight percent of the total 10 million green tons was estimated to have inadequate markets (Parhizkar, 2008).

Another regional study that covered only the three states of Virginia, North Carolina, and South Carolina (Galik, Abt, and Wu, 2009) concluded there are 1.3 million dry tons (or 2.6 million green tons) of forest residues potentially available in Virginia (Galik, 2009). Galik et al. assumed a 50-percent recovery rate for logging residues.

Table 3. Estimates of Forest Residues in Virginia from Recent Published Studies

	Estimates of Forest Residues
Parhizkar and Smith (2008)	770,000 green tons
Galik, Abt, and Wu (2009)	2.6 million green tons
Conner and Johnson (2011)	4.8 million green tons

Table 3 above presents the wide range of estimates of forest residues in Virginia from recent published studies. When considering the 4.8 million green ton figure from the Conner and Johnson study, it is important to note that they quantified both logging residues from current harvesting activities and the amount of additional "standing residual inventory" left uncut by these harvests. Inclusion of this material is the prime reason for such high estimates.

1.3.3.2 North Carolina

Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential.

In the recently released (June 2011) La Capra report prepared for the North Carolina Energy Policy Council, the authors provided detailed estimates of biomass resources that could be used to help meet renewable energy targets in North Carolina (La Capra Associates, 2011). This analysis included estimates and projections for forest biomass, urban wood waste, and agriculture from within North Carolina and also select counties in Virginia and South Carolina (those covered within Duke Energy and Progressive Energy service territory). For this report, La Capra employed the services of Robert Abt, Christopher Galik, and Karen Abt who conducted detailed modeling using the SRTS model used in numerous other studies to forecast the supply of biomass fuel into the future under different sets of parameters.

Using this modeling method, the study team provided estimates of both the technical potential for supply and the practical potential for supply.[4] For the *technical* potential they estimated 6.73 million dry tons of logging residues and another 7.73 million dry tons of pulpwood (these recovery rates are generally considered to be on the high end of the range of what is viable).[5] It is important to note this estimate is not presented by the authors as the preferable scenario—its intent was to present an upper limit.

Accordingly, they provided a more realistic scenario of the resource capacity to expand biomass energy without the likelihood of adversely affecting the forest ecosystems and avoiding displacement of wood currently supplying the traditional forest products industry.[6] For the *practical* potential model runs, however, the supply was not modeled based on ecological constraints and layering in the demand levels of the traditional forest products industry. Instead, demand scenarios from expanded biomass energy markets were plugged into the model to see both their impact on the forest residue resource base and how much displacement of pulpwood would occur as a result after residue resources were exhausted. In other words the authors assumed that more demand for biomass would be met first by tapping into existing amounts of logging residues and then by taking some pulpwood away from current pulpwood markets with no net increase in pulpwood harvesting—rather than assuming that pulpwood for biomass fuel would result in a net increase in pulpwood harvesting.

1. WOOD SUPPLY REVIEW *(cont'd)*

Several scenarios were modeled and La Capra Associates concluded for the practical run that in the Duke /Progress service area in 2011, there are 11.6 million green tons (5.8 million dry tons) annually all from residues, or enough to support more than 1,000 MW of power plant capacity. As they modeled demand further into the future, the amount of pulpwood required by biomass energy plants increased (the threshold was estimated at about 12 million tons per year).

The La Capra report also concluded that for a biomass power plant to operate cost effectively given the capped incremental revenue of $35/MWh ($0.035 per kWh), the wood fuel cost for a 15-year period could not exceed $7.34 per green ton on a stumpage basis or $20.40 per green ton for delivered fuel. Yet evidence exists suggesting that power plants routinely pay more than $20 per green ton. Average second-quarter (2011) softwood chip prices paid by pulpmills in the southeastern United States was $35.50 per green ton. Given the incremental price cap and the current pulp value of wood fiber, there is little evidence to suggest a strong likelihood of displacement. If anything, the growth of the pellet market will have the greatest displacement potential of pulpwood because this growing market requires the fiber quality found in pulpwood and not in harvest residues.

It is important to note that many econometric studies, including the LaCapra study, present potential biomass fuel availability as a function of price and use the *stumpage* pricing paid for biomass and pulp as an indicator of the extent that biomass markets may displace pulp mill supply by turning to roundwood. While in some circumstances stumpage prices paid by the facilities directly to the landowner can dictate where the cut wood goes (and the logger is paid to merely cut and haul the wood to the given market), there are other situations where it is the *market* price paid at the wood processing facility's gate that dictates to which market cut wood flows. Such is the case with a timber sale where the logger pays the landowner stumpage and the logger decides where to take the wood based on where they can make the most profit (factoring transport costs and price paid at the gate).

Using a more conservative assumed harvest residue recovery rate of 50 percent, Galik, Abt, and Wu (2009) concluded there are only 2.8 million dry tons (5.6 million green tons) of forest residues available in North Carolina—less than half of the amount LaCapra estimates (LaCapra Associates, 2011). This lower harvest residue figure would dramatically reduce (from the LaCapra estimate of potential) the amount of electrical energy that could be generated from wood residues in North Carolina.

1.3.3.3 South Carolina

In April 2006, the South Carolina Energy Office released a report entitled, Biomass Energy Potential in South Carolina: A Conspectus of Relevant Information. This report was later revised and re-released in August 2008. This study examined the potential for direct combustion from solid biomass; methane production from various farm, municipal, and industrial wastes; and ethanol production from farm crops and residues. The study cites work previously conducted in the state that concluded there were 22 million green tons of woody biomass resources annually for biomass energy (Harris, 2004). Of these 22 million green tons, only 4.4 million were from logging residues.

Again, using the more up-to-date data, more sophisticated modeling, and a more conservative assumed rate of harvest residue recovery, Galik, Abt, and Wu concluded there are 1.8 million dry tons (3.6 million green tons) of forest residues potentially available in South Carolina.[7]

1.3.3.4 Georgia

The Georgia Forestry Commission's website reports its 2009 findings of an estimated 9.1 million dry tons more wood than what is being removed each year (Georgia Forestry Commission, 2009). A summary table presented on the commission's website provides nearly no background on the data source or methods used to come to this estimate, however, it does provide an itemized list of the various categories that add up to the 9.1 million dry tons. Figure 3 below is the summary table.

There is no clear indication where the information in the table comes from and what methods were used to make these estimates. It is also unclear whether these are intended to represent annual volumes. Furthermore, there is no clear indication whether the figures given in the "Inventory Amount" column are in units of green tons, dry tons, cubic feet, or some other unit of measure. It is assumed that the "Inventory Amount" column represents the total forest standing inventory and that the "Recovery Rate" column shows the annual rate of recovery. According to the Forestry Commission, there are 3.88 million green tons of logging residues generated annually in Georgia (assuming a 100 percent recovery rate).

Forestry Biomass Estimates for Georgia, General Statewide Assessments, 2009

Resource		Inventory Amount	Recovery Rate	Amount to Recover (oven dry ton basis)
"Non-merchantable" biomass inventory in forests	Recovery during regeneration harvests	163,300,000	1.4%	2,286,200
"Non-merchantable" biomass inventory in forests	Recovery during thinnings	163,300,000	1.0%	1,633,000
Biomass from "pre-commercial" thinning of natural forest stands of pine and pine/hardwood		46,388,654	1.0%	463,887
Logging residues produced annually in forest management operations (excluding stumps)	From growing stock	1,940,250	100.0%	1,940,250
	From non-growing stock (included in non-merchantable biomass)	1,726,920	0.0%	0
Other annual timber removals resulting from land-use change	Estimate 75% recovery	1,834,625	75.0%	1,375,969
Mill residues produced annually		7,305,000	0.0%	0
Recoverable urban wood waste annually		1,436,823	100.0%	1,436,823
			Total	9,136,128

Figure 3.

Summary table of estimated dry tons of wood removed from Georgia each year.

1. WOOD SUPPLY REVIEW *(cont'd)*

Florida's forest resources lay mostly in the northern part of the state whereas many of the other states in the region have fairly even geographic distribution of their forest resources.

1.3.3.5 Florida

In March 2010, the University of Florida released a report entitled, Woody Biomass for Electricity Generation in Florida: Bioeconomic Impacts under a Proposed Renewable Portfolio Standard (RPS) Mandate. In the report the authors, Rossi, Carter, and Abt, explore the resource supply response to the possibility of mandatory RPS of 20 percent renewables by the year 2021. The authors model various scenarios, including the use of merchantable timber, urban wood waste, and logging residues.

In this study, the authors assume that a large percentage of the 20 percent renewable energy target will come from woody biomass energy based on the assertion that other renewables like wind and solar have both technological and cost constraints. Rossi et al. found that logging residues and urban wood waste resources in Florida "do not comprise a significant amount of aggregate supply of woody biomass required under a 20 percent RPS." Furthermore, they concluded that a significant portion of the demand presented by a 20 percent RPS would need to be met using merchantable timber. It is important to note that the authors have assumed that 100 percent of the RPS would be met from woody biomass energy and nothing would come from other renewable sources.

The authors state in the executive summary, "It is widely assumed that Florida's abundant wood resources would be relied upon in order to meet much of the RPS-imposed demands for electricity, given that factors such as technological constraints and cost considerations will combine to limit the amount of renewable energy that will come from solar, wind, and other sources of renewable energy" (Rossi, 2010). There is no clear evidence to support or dispute this statement by Rossi, et al. Certainly, representatives from the wind, solar, and biogas energy industries would dispute the validity of this assertion.

Anecdotally, it is important to keep in mind that Florida's forest resources lay mostly in the northern part of the state whereas many of the other states in the region have fairly even geographic distribution of their forest resources.

1.3.3.6 Alabama

In June 2009, the Alabama Forestry commission released a report entitled, Woody Biomass Energy Opportunities in Alabama. Only very basic information regarding potential supply and demand of biomass resources is provided in this report.

1.3.3.7 Tennessee

No further studies were found for Tennessee.

1.4.0 APPLES-TO-APPLES BIOMASS RESOURCE ASSESSMENT OF SEVEN-STATE REGION

1.4.1 Summary of Wood Residues

Due to the fact that each of the studies detailed on the previous pages looked at different groups of biomass resources, quantified the resource with and without also quantifying the current use, used different data sources and different methodologies, and studied different geographic regions, there is no rational way to weave together all the various disparate studies and bits of information. To supplement the bits and pieces of state-specific information from all the various sources and studies presented earlier, the Table 4 below was created by BERC to present a consistent set of information for the biomass resource for each of the seven states.[8] It presents information assembled into fact sheets for numerous southern states by the SUN Grant initiative (Southern Forest Research Partnership, 2011).

The information presented in Table 4 is useful, yet must be put into the proper context. While nearly 50 million dry tons of annual woody biomass generation in the seven-state region may seem like a lot of biomass, without knowing how much of that amount is already being used by existing markets, it is somewhat meaningless. A large majority of recent fuel supply studies have concluded that nearly all primary and secondary wood processing mill residue (chips, sawdust, wood flour, shavings, and bark) and urban wood waste are already being utilized by wide-ranging existing markets. Pulpmills have long utilized paper-grade chips from sawmills. Many wood processors also use their own wood residues to fuel their kiln drying of lumber. Also some sawmills in the region have added pellet mills to their operations, thereby further utilizing their own residues. Agricultural markets have long been a steady outlet for sawdust and shavings for animal bedding. The landscaping and horti-

A large majority of recent fuel supply studies have concluded that nearly all primary and secondary wood processing mill residue (chips, sawdust, wood flour, shavings, and bark) and urban wood waste are already being utilized by wide-ranging existing markets.

Table 4. Biomass Resource for Each of the Seven States

	Urban Wood (DT/yr)	Mill Residues (DT/yr)	Harvest Residue (DT/yr)	Total (DT/yr)
Virginia	813,000	800,926	1,700,000	3,313,926
North Carolina	833,000	5,000,000	2,300,000	8,133,000
South Carolina	467,000	2,400,000	1,600,000	4,467,000
Georgia	1,440,000	8,000,000	3,500,000	12,940,000
Florida	4,600,000	2,600,000	1,300,000	8,500,000
Alabama	100,000	6,800,000	2,700,000	9,600,000
Tennessee	614,000	577,000	760,000	1,951,000
TOTAL	**8,867,000**	**26,177,926**	**13,860,000**	**48,904,926**

1. WOOD SUPPLY REVIEW *(cont'd)*

To give an accurate picture of whether the broader forest resource could support the potential increased demand from biomass energy beyond just the use of harvest residues, a detailed analysis for the seven-state region is needed.

culture markets have been a consistent outlet for bark (especially softwood species). Composting operations also rely on wood residues as a feedstock for mixing with sewage sludge, farm manure, and food wastes. Composite wood products industries such as particle board and oriented-strand board use various wood residues. Food flavoring industries like meat smoking use wood wastes as well. Unfortunately, little data exist on the exact consumption from each of these markets for the seven-state region.

Of the three categories listed in Table 4, it can be generally assumed that harvest residues (13.86 million dry tons per year for the seven states) are the untapped resource. It should be noted again, however, that to cost effectively extract these residues, whole-tree harvesting systems are essential. Therefore, the portion of the harvest residues generated by mechanical cut-to-length and manual stem-only harvesting are not accessible. None of the studies assessed in the literature review directly mention this point.

1.4.2 Summary of Forest Capacity for Harvested Wood Fuel Beyond "Residues"

While harvest residues have a certain potential to supply future growth of biomass energy in the southeastern United States, there is a limit to how far these resources can go in light of the gradual decline in timber harvesting over the past decade. Less wood cut for traditional markets equals fewer residues for biomass energy. At some point, biomass markets may prefer a more reliable source of fuel coming from wood harvested for the purpose of energy. Few of the studies examined in the literature review explore this potential.

To give an accurate picture of whether the broader forest resource could support the potential increased demand from biomass energy beyond just the use of harvest residues, a detailed analysis for the seven-state region is needed. This was not feasible given the scope, timeline, and budget of this study. The following section provides an extremely basic and overly simplified assessment of the forest resource to supply wood above and beyond the current demands. *This information is not intended to present accurate estimations; these numbers are for conversational purposes only.* It should be noted that forests are extremely complex and dynamic systems and any effort to quantify their inventory, growth, and capacity to supply additional amounts of wood fuel should be interpreted as being an oversimplification with a wide margin of error.

In an effort to examine the potential capacity for expanded use of forest biomass evenly across the seven-state region using consistent data and methods that are "apples to apples," we used an approach that would provide a quick-glimpse sense of the resource capacity. This approach makes numerous assumptions and takes several basic steps:

1. Assume that all the urban wood, and primary and secondary wood residues all have existing markets and that any new market growth for biomass energy will be met with harvested wood
2. Identify the total forestland land area in the seven-state region
3. Identify the total amount of standing forest inventory on that forestland footprint
4. Identify the amount of net annual growth[9] of new wood

Table 5. USDA Forest Service FIA Data for Seven-State Region[10,11]

	Forestland Area (Acres)	Total Inventory[12] (GT)	Net Growth (GT)	Removals (GT)	Net (GT)
Virginia	15,900,000	1,009,323,529	30,117,647	19,173,235	**10,944,412**
North Carolina	18,600,000	1,052,941,176	43,000,000	33,764,706	**9,235,294**
South Carolina	12,900,000	632,352,941	35,294,118	19,676,471	**15,617,647**
Georgia	24,800,000	1,102,941,176	58,823,529	47,058,824	**11,764,706**
Florida	16,900,000	567,647,059	23,823,529	17,617,647	**6,205,882**
Alabama	22,900,000	835,294,118	49,676,471	37,705,882	**11,970,588**
Tennessee	13,800,000	761,764,706	24,941,176	17,647,059	**7,294,118**
TOTAL	**125,800,000**	**5,962,264,706**	**265,676,471**	**192,643,824**	**73,032,647**

5. Identify and subtract the rate of annual removals for the seven-state region
6. Calculate the net supply of annual growth beyond current removals
7. Make more assumptions regarding the percentage of this amount that is available

Table 5 above presents this approach in detail for each state.

Knowing how much the forests are growing and what level of harvest can be sustained over time gives a basic picture of wood fuel availability and the viability of woody biomass energy.

When forests are examined from a broad perspective, wood inventory can be compared to money invested in a bank account that earns interest annually. The total annual growth of trees in a forest is analogous to the interest earned on capital invested. A wise financial investor strives to spend only the annual interest earned each year and not dip into the principal. Forests are the same: Sound forest management policy within a state or region limits harvesting to within a range that approximates the amount of annual growth so that growth-to-removal ratios are maintained in rough equilibrium.

For the purpose of this assessment, the net annual growth of new amounts of wood was chosen as the indicator of how much wood the forests of these states can provide on a sustained-yield basis.

On the surface, the data presented above indicates that there is more than 73 million green tons of annual growth of new wood beyond the current demands for timber products in the seven-state region. It should be noted, however, that the FIA data above is focused on the growing stock portion of the total forest inventory and does not account for the amount of top and limb wood. Thus, in theory there is more than that. While 73 million green tons of new wood annually seems like a lot, the reality is that it is dramatically less. Forest management and periodic harvesting occurs only on a portion of the forested footprint and therefore, physical, ecological, and social constraints on the land area

1. WOOD SUPPLY REVIEW *(cont'd)*

on which supply is estimated must be taken into account. Normally, detailed modeling would be conducted to factor such constraints (steep slopes, stream buffers, critical wildlife habitat, landowner attitudes, parcel size, etc.), but as that was beyond the scope of this study, we applied an overly simplistic assumption of 50 percent reduction to crudely account for these factors. This yields an estimated 36.5 million green tons of un-utilized annual growth beyond current market demands. This assumes that all of this annual growth beyond current removals would be available exclusively to energy markets and would not simultaneously feed other traditional timber markets. This is an unlikely scenario even though some forecasts indicate that no other wood market is poised to grow as significantly in the future as biomass energy.

If all this wood was utilized for biomass energy in the future, it translates to an average increase in harvesting of 0.58 green tons per acre per year (spread over the total forested footprint of each state). This 36.5 million green ton amount will be revisited in greater detail in Section 1.5.2. Again, it must be emphasized that these numbers are for discussion purposes only and do not represent any estimates (implied or otherwise) by the authors of how much wood could actually be available in the future.

1.5.0 ASSESSMENT OF THE RENEWABLE PORTFOLIO STANDARDS

This section explores both the existing state RPS (mandatory and voluntary) and the potential for a federal Renewable Energy Standard.

1.5.1 Current State Renewable Energy Portfolio Standards

At the present time, only three of the seven states in this study area have Renewable Energy Standards—Virginia, North Carolina, and Florida. Of these three states, only North Carolina's standard is mandatory—Virginia and Florida's are voluntary. The following section provides further details of these current standards.

1.5.1.1 Virginia

Virginia enacted a *voluntary* renewable energy portfolio goal in 2007 and further legislation was passed in 2009 to expand the goal—encouraging investor-owned utilities to purchase a percentage of the power sold from renewable energy sources. In addition, the Commonwealth of Virginia offers a performance incentive to participating utilities in the form of an increased rate of return (profit) for each "RPS Goal" attained. Electricity must be generated or purchased in Virginia or in the interconnection area of the regional transmission entity.

The voluntary targets set out in the standard are defined as percentages of the amount of electricity sold in 2007 (the "base year"), minus the average annual percentage of power supplied from nuclear generators between 2004 and 2006.

Table 6. Virginia RPS Schedule

	Target
RPS Goal I:	4% of base year sales in 2010
RPS Goal II	Average of 4% of base year sales in 2011 through 2015, and 7% of base year sales in 2016
RPS Goal III	Average of 7% of base year sales in 2017 through 2021, and 12% of base year sales in 2022
RPS Goal IV	Average of 12% of base year sales in 2023 and 2024, and 15% of base year sales in 2025

Investor-owned electric utilities can gain approval to participate in the voluntary RPS program from the Virginia State Corporation Commission, the entity that oversees utilities, if the utility demonstrates that it has a reasonable expectation of achieving the 12 percent target in 2022.

Eligible energy resources include solar, wind, geothermal, hydropower, wave, tidal, and biomass[13] energy.

- Onshore wind and solar power receive a double credit toward RPS goals
- Offshore wind receives triple credit toward RPS goals
- Existing renewable energy generators like older hydro are eligible for RPS compliance

1.5.1.2 North Carolina

North Carolina's Renewable Energy and Energy Efficiency Portfolio Standard (REEPS) was established by Senate Bill 3 in August 2007. It requires all investor-owned utilities in the state to supply 12.5 percent of 2020 retail electricity sales (in North Carolina) from eligible energy resources by 2021. Municipal utilities and electric cooperatives must meet a target of 10 percent renewables by 2018.

Under this standard, eligible energy resources include solar-electric, solar-thermal, wind, small hydropower, ocean wave energy, biomass, landfill gas, CHP using waste heat from renewables, hydrogen derived from renewables, and electricity-demand reduction. Up to 25 percent of the requirement may be met through energy efficiency technologies, including CHP systems powered by non-renewable fuels. After 2021, up to 40 percent of the standard may be met through energy efficiency.

The overall target for renewable energy includes technology-specific targets "carve outs" or "set asides" of 0.2 percent solar by 2018, 0.2 percent energy recovery from swine waste by 2018, and 900,000 megawatt-hours (MWh) of electricity derived from poultry waste by 2014.

The compliance schedule for investor-owned utilities appears in Table 7 on the following page.[14]

1. WOOD SUPPLY REVIEW *(cont'd)*

A typical biomass power generation plant of 20 MW per hour capacity would require approximately 250,000 green tons of woody biomass fuel annually.

Table 7. Compliance Schedule for Investor-Owned Utilities

Year	Percent Target from Eligible Renewable Energy	"Set Asides" for Specific Sources
2010	0.02%	From solar
2012	3%	0.07% from solar 0.07% from swine waste 170,000 MWh from poultry waste
2013	3%	0.07% from solar 0.07% from swine waste 700,000 MWh from poultry waste
2014	3%	0.07% from solar 0.07% from swine waste 900,000 MWh from poultry waste
2015	6%	0.14% from solar 0.14% from swine waste 900,000 MWh from poultry waste
2018	10%	0.20% from solar 0.20% from swine waste 900,000 MWh from poultry waste
2021	12.5%	including 0.20% from solar + 0.20% from swine waste + 900,000 MWh from poultry waste

Utilities must demonstrate compliance by purchasing renewable energy credits (RECs) and a REC is equivalent to 1 MWh of electricity derived from a renewable energy source, or an equivalent amount of thermal energy in the case of CHP and solar water heating, or 1 MWh of electricity avoided through an efficiency measure. Any excess RECs accumulated by a utility may be applied to the next year's compliance target. Utilities may use unbundled RECs from out-of-state renewable energy facilities to meet up to 25 percent of the portfolio standard.

It is important to note that there is no minimum target for biomass energy from woody biomass sources, however, the commission will provide triple credit for every one REC generated by the first 20 MW of a biomass facility located at a "cleanfields renewable energy demonstration park." A typical biomass power generation plant of 20 MW per hour capacity would require approximately 250,000 green tons of woody biomass fuel annually.

1.5.1.3 Florida

Florida does not have a state-wide RES, however, in November 1999, JEA, a municipal utility servicing the greater Jacksonville area, signed a Memorandum of Understanding with the Sierra Club and the American Lung Association of Florida to formalize the municipal utility's commitment to generate at least 7.5 percent of its electric capacity from green energy sources by 2015. Eligible renewable energy resources include solar, biomass, biogas (methane from landfills and sewage treatment plants), and wind as well as specific efficiency projects.

1.5.1.4 Discussion of Current State Standards

It is unclear how much, if any, new woody biomass electric generation capacity will occur as a direct result of the voluntary standards set in Florida or Virginia. Although North Carolina has a mandatory standard for specific levels of renewable energy by specific dates, it is also unclear how much, if any, new biomass power generation capacity will be developed as a direct result of this policy. Certainly the triple credit applied to the first 20 MW of capacity of a biomass plant in North Carolina is a strong incentive that could result in an additional demand of 250,000 green tons of woody biomass. Given the emphasis on both poultry and swine manure in the North Carolina standard, it is also feasible that the first 20 MW that receives this triple REC credit could be fired with farm manure rather than wood.

Without any "set aside" specifically for woody biomass, it is unclear how much, if any, biomass energy development will result directly from these policies. Will other renewables (wind, solar, hydro, swine or poultry manure) be developed first and meet the targets? Will a REC price go high enough to make electric generation using woody biomass more attractive to developers? Any effort to predict the cause-and-effect relationship between a voluntary or mandatory RPS and the resulting demand from forests is highly speculative at best.

Yet, numerous new biomass power plants are being proposed as well as proposals to convert existing coal plants to burn biomass fuel. Given the flurry of biomass project proposals prior to the existence of any meaningful RPS, the question becomes what is currently driving this development activity? There are several modest incentives available to biomass power plants that improve the economics beyond market wholesale rates for sale of electricity. Interviews with plant managers and experts in the field of electric power regulation and development and further analyses of federal subsidies indicate that, generally, the most important current federal incentive is the Production Tax Credit, or PTC ($10 per MWh). Select states in the United States such as Massachusetts have adopted aggressive RPS policies that have created RECs ranging $0.02-$0.03 per kWh. While the value of a REC is higher, the price varies significantly in the marketplace with the cycling of RPS requirements, emergence of new technologies, construction of new renewable energy facilities, the state of the economy, and demand for electric power. While less valuable at only $10/MWh, the federal PTC is a more stable source of income for biomass plants over time.

Without, a clear economic incentive like a REC or the PTC for the biomass plants, many utilities in the Southeast proposing to build biomass power plants would likely be forced to request a rate increase from the state regulatory agencies to absorb the higher costs of electricity from biomass. While dozens of proposals to build biomass power plants are under development, historically only a very small percentage of the total proposals ever get built.

While dozens of proposals to build biomass power plants are under development, historically only a very small percentage of the total proposals ever get built.

1. WOOD SUPPLY REVIEW *(cont'd)*

1.5.2 Potential for a National Renewable Energy Portfolio Standard

For the purpose of this study, we were asked to explore the impact of the passage of a federal RES. There are currently 36 states in the United States with some form of a RES and these state standards vary widely in their target percentages and due dates. The resulting patchwork of energy policies is often confusing and chaotic. In 2010, a group of six US senators introduced a bill to adopt a federal RES. While the bill did not pass, it has raised the energy sector's awareness of what impact such a federal standard could have on our energy portfolio in the future.

At this time, it is unclear that if a federal standard were passed, what the overall target percentage, the target dates, and what specific "set asides" for various allowable technologies would be. Furthermore, the extent that each state had to meet these federal targets on their own or whether the targets could be met when averaged for all 50 states, is also unknown. There is no reliable way to predict how much woody biomass demand would be created by the passage of a federal RES at this time.

Given the numerous variables and uncertainties mentioned, and in an effort to explore the impacts of a federal RES, we must make some assumptions to form a series of "what if" scenarios. Let's start with the assumption that a federal RES is applied evenly to each state and requires compliance at the state level, not averaged up to the national level. Let's also assume that the federal RES contains a specific "set aside" for biomass and more specifically for woody biomass as a subset to the biomass category.

Table 8. US Energy Information Administration State Energy Data System – 2009 Electric Consumption

	Total Electric Consumption (trillions of Btu)
Virginia	370.1
North Carolina	435.6
South Carolina	260.7
Georgia	446.2
Florida	766.8
Alabama	282.7
Tennessee	322.9
TOTAL	**2,885.0**

Tables 9 and 10 below examine a scenario where a federal 15 percent RES target is achieved using forest biomass as fuel to achieve 20 percent of that overall target (or 3 percent of the total).

Table 9. Calculated Target Amount of Energy to Be Met from Biomass

	RPS Target	Resulting Amount of Energy (trillions of Btu)	Assumed % for Biomass	Amount of Energy from Biomass (trillions of Btu)
Virginia	15%	55.5	20%	11.1
North Carolina	15%	65.3	20%	13.1
South Carolina	15%	39.1	20%	7.8
Georgia	15%	66.9	20%	13.4
Florida	15%	115.0	20%	23.0
Alabama	15%	42.4	20%	8.5
Tennessee	15%	48.4	20%	9.7
TOTAL		**432.8**		**86.6**

Assuming 1.22 green tons per MWh (e). Numbers may not sum due to rounding.

Table 10. Comparison of Wood Needed to Meet Target and Estimated Supply

	50% of Annual Growth beyond Annual Harvest (as calculated in Section 1.4.2)	Green Tons Required to Meet 15% RES with 20% from Forest Biomass	Difference
Virginia	5,472,206	3,977,237	1,494,969
North Carolina	4,617,647	4,681,125	-63,478
South Carolina	7,808,824	2,801,583	5,007,241
Georgia	5,882,353	4,795,037	1,087,316
Florida	3,102,941	8,240,328	-5,137,387
Alabama	5,985,294	3,038,003	2,947,291
Tennessee	3,647,059	3,470,008	177,051
TOTAL	36,516,324	**31,003,322**	5,513,003

Numbers may not sum due to rounding.

1. WOOD SUPPLY REVIEW *(cont'd)*

In Section 1.4.2, we calculated (in grossly oversimplified terms) that there is 36.5 million green tons of forest capacity (new annual forest growth in excess of current removals), and that to meet a 15 percent federal RES with 20 percent coming from woody biomass, approximately 31 million green tons would be needed. While the total number of tons needed to meet the federal RES targets are less than the calculated values representing the total potential resource, on the state level, both Florida and North Carolina indicate a greater demand for woody biomass than the supply from forest biomass.

Sensitivity analysis indicates that when the percentage of the 15 percent RES that comes from woody biomass is decreased from 20 percent to 15 percent, all states with the exception of Florida have sufficient resources to meet the potential demand from that policy scenario. In Florida, even when the percentage is further lowered to 10 percent coming from woody biomass, our calculations indicate insufficient woody biomass resources. Florida has considerable forest resources in the northern half of the state, but this result is due to the extremely high levels of electric demand in Florida—nearly twice that of the second largest consumer of electricity, Georgia.

Table 11. Comparison of Wood Needed to Meet Target and Estimated Supply

	50% of Annual Growth beyond Annual Harvest (as calculated in Section 1.4.2)	Green Tons Required to Meet 15% RES with 30% from Forest Biomass	Difference
Virginia	5,472,206	5,965,856	-493,650
North Carolina	4,617,647	7,021,688	-2,404,041
South Carolina	7,808,824	4,202,374	3,606,450
Georgia	5,882,353	7,192,556	-1,310,203
Florida	3,102,941	12,360,492	-9,257,551
Alabama	5,985,294	4,557,005	1,428,289
Tennessee	3,647,059	5,205,012	-1,557,953
TOTAL	**36,516,324**	**46,504,982**	**-9,988,658**

Numbers may not sum due to rounding.

On the contrary, when the sensitivity analysis increased the amount of woody biomass contributing toward a 15 percent RES from 20 to 30 percent, more than 46 million green tons were required—leaving nearly all the states (with the exception of South Carolina and Alabama) in a woody biomass deficit. Table 11 on the previous page illustrates the conceptual outcome of meeting a 15 percent federal RES with 30 percent coming from forest biomass in the seven-state region. Under this scenario only South Carolina and Alabama have sufficient in-state forest resources to meet the state-level energy targets.

It is important to note that our calculations do not closely match with the model runs conducted by Galik and Abt because our crude calculations were static projections of growth over removals and do not directly account for any displacement of pulpwood. The Galik and Abt study used sophisticated models that accounted for some levels of displacement of pulpwood harvest over time. Any number of further scenarios of different federal RES levels and different woody biomass targets could be calculated but that did not fall within the scope of this study.

Because there was no significant shortfall in woody biomass resources when a 15 percent RES using 20 percent woody biomass was examined, no further assessment of agricultural residues or dedicated energy crops were required to meet this particular demand scenario. With a 30 percent biomass component for a 15 percent RES, however, there is a significant woody biomass deficit in most of the study states. Furthermore, if the pellet market continues to expand and increases its wood sourcing throughout the southeastern United States, further constraints would be placed on the resource and a 15 percent RES using 20 percent woody biomass may have difficulty achieving its target. Of course, conversely, if several pulpmills in the southeastern region shut down in the near future, that would free up a considerable amount of wood supply.

1. WOOD SUPPLY REVIEW *(cont'd)*

1.6.0 REVIEW OF FEDERAL RENEWABLE FUELS STANDARD

The federal Renewable Fuels Standard (RFS) program was established under the Energy Policy Act of 2005 and created the first renewable fuel mandate of 7.5 billion gallons of renewable fuel to be blended into gasoline by 2012. A proposed update is under development by EPA with a planned release date of November 2011 for the compliance year of 2013. The proposed targets call for a mixture of cellulosic biofuel, biomass-based diesel, advanced biofuel, and renewable fuel adding up to 15.2 billion gallons of equivalent ethanol (EPA, 2011).

A federal RFS could have an impact on woody biomass resources and several years ago there was strong evidence to suggest that cellulosic ethanol would have a major role in the future demand put on our forests. Over the past two or three years, however, less emphasis has been given to this use due to the continuing struggles to achieve commercialized production of cellulosic ethanol from wood fibers.

"One potential driver of demand for forest biomass is the federal Renewable Fuel Standard (RFS), which sets minimum standards for how much gasoline and diesel fuel must be produced from renewable sources each year. However, the initial announced targets have been steadily lowered in the face of shortfalls in production, and it is expected that energy crops and other sources would likely be preferred over wood feedstock for producing cellulosic ethanol. Our model runs therefore assume no forest biomass is used to meet RFS-driven demand for biofuels." (La Capra Associates, 2011)

Because all evidence clearly suggests that woody biomass will play only a minor role in producing liquid transportation fuels and that the technology development to implement such a demand is still years away, we have chosen to not explore the implications further.

For hypothetical purposes, let's explore the 36.5 million green tons of conceptual annual supply from the seven-state region, and see how many gallons of cellulosic ethanol that would yield (assuming fully commercialized plants get built). Assuming a yield of 40 gallons per green ton, nearly 1.5 billion gallons of ethanol could be produced, leaving no further woody biomass resources for expansion of any other market. This would account for slightly less than 10 percent of the national RFS2 target (US Department of Energy EERE, 2011). If cellulosic ethanol production expands in the near future, however, there is a high likelihood that agricultural biomass resources will contribute significantly.

1.7.0 CONCLUSIONS

Most studies conducted in the past six years quantify the gross or total amount of woody biomass material generated on an annual basis and do not quantify how much is already being used. Most of these studies focus on residues produced from other primary activities while evidence suggests nearly all the mill and urban wood residues are already used by existing markets.

The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).

Whether logging slash, whole trees, or pulpwood will be used by the expansion of biomass energy in the future will depend on:

1. Which market the wood is going to (pellet mills need high-quality fiber from pulpwood and biomass plants are less particular about quality)
2. How much demand increases within the pellet and power market sectors over time
3. What happens with the pulp and paper industry in the southeast region in the future

Prior to 2009, most fuel availability studies presented estimates of supply without any acknowledgment of the influence price has on the availability of these woody biomass resources. Since then, most fuel supply assessments have begun factoring the economics and present the availability of the resources as supply curves depicting the amount of material potentially available at different price points. The original and the updated Billion-Ton Study are good examples.

It is important to point out that different studies have examined the economics using different indicators, making it difficult to compare results among the studies. Several studies only examined stumpage prices paid to landowners (Galik and Abt, 2011) for wood fuel, which do not reflect any cost to harvest, extract, process, or transport, while other studies focus exclusively on prices paid "roadside" for yarded wood (Perlack and Stokes, 2011), which do not reflect the cost of transport. Still other studies focus on the total delivered prices paid at processing facilities (mills or power plants). For a clear assessment of the economics of woody biomass resources, the total delivered price paid by the receiving facilities is the best indicator to use.

Various studies reviewed in this chapter used widely divergent assumptions regarding what percentage of the total amount of logging residue can be recovered from a harvested area. The range observed in the studies was from roughly 50-100 percent. While examining how much wood fuel could be generated if 100 percent of this material was recovered may be useful for academic purposes, it is unrealistic to assume that such a high level can and should be realized. It is unclear from these studies whether these recovery rates are intended to be applied to all harvest operations where only a percentage of the residue is gathered—factoring logistical and ecological reasons for not recovering more—or if this recovery rate applies to taking all residues from only a percentage of the harvest operations. This is an important point because ideally, a study would look at both issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered.

The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).

1. WOOD SUPPLY REVIEW *(cont'd)*

Logging residue amounts will be difficult to access due to extraction methods. Where whole-tree harvesting systems can be used, these residues can be cost-effectively accessed. Where mechanized cut-to-length and manual stem-only harvesting are used, these residues will not be easily accessible. Further analysis determining how much whole-tree harvesting systems versus stem-only-harvesting systems are used in this region would be very useful.

Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential. Alabama and Tennessee both had very little publicly available reports estimating biomass resources.

Our quick supply estimate exercise suggests that there is likely enough wood supply in the forests to meet a 15 percent federal RES standard applied to each of the seven states (with the exception of Florida and possibly North Carolina) when woody biomass sourced from local forests accounts for no more than 20 percent of the overall renewable generation target. It also appears, however, that adequate wood resources are quite sensitive to the RES allocation; if for example 30 percent of a 15 percent RES was allocated to forest biomass, it is likely there would not be enough wood fuel available within the region. A more aggressive RES standard for biomass leads to a higher likelihood of shortages and a greater probability of pulpwood displacement.

Capacity to access and utilize residues is also a function of how much roundwood harvest occurs. More demand for roundwood generates more residues. The extent to which biomass power plants transition their wood procurement away from residues and toward roundwood is governed by the strength of the rest of the forest products industry. If the forest products industry strengthens as a result of greater lumber demand, they will increase their wood fiber consumption and as a result, biomass power plants will be able to procure more residues at a lower cost and less pulpwood at a higher cost. If the forest products industry as a whole continues to contract, however, biomass power plants will likely transition toward procurement of chipped fuel from whole-trees *assuming* they can absorb the higher cost associated with that transition. Future demand for roundwood from the pulp and pellet industries will play a role in determining how much roundwood is used for power production.

While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood. In fact, this is already happening. If pellet demand continues to grow and results in increased levels of roundwood harvest, then pellets may well determine the future level of harvest residue available for the power plants to utilize.

Therefore, pellet mills and biomass power plants have somewhat complementary (almost symbiotic) procurement needs. Pellet production, especially the export market to Europe, will continue to play the wildcard role.

While this report has identified and probed some of the issues regarding the forest resource's capacity to produce more energy in the Southeast, there are numerous areas where key information is missing. More specific research is needed in the areas of: existing forest residue utilization, use of different harvesting systems, a comprehensive wood fiber assessment for the entire seven state region, the price elasticity of demand between fuel chips and pulpwood, and the likely impacts of federal renewable energy standards on the economic incentives that drive project development. In addition, further study is needed to explore the relation biomass sourcing has on harvest intensity and the potential impacts on forest biodiversity, wildlife habitat, water quality, and soil health and productivity.

2. TECHNOLOGY PATHWAYS

2.1.0 INTRODUCTION TO TECHNOLOGY PATHWAYS

This discussion focuses on those technologies and applications—electricty generation and CHP—that are already well established, or are technologically achievable in the immediate future should policies wish to guide additional biomass in these directions.

Biomass in various forms can be used for a range of energy options, through a variety of technologies, to achieve various end purposes. In this chapter, several pathways are examined to give the reader an understanding of this range, but also to inform and model potential demand for fuel supply in the future and understand the carbon implications for these choices. This assessment looks at the use of existing low-grade forest resources in the seven-state study region as well as switchgrass, an agricultural crop that can also be pelletized and used directly for biomass energy. Other sources of nonforest-based biomass—such as wood waste from construction debris or other sources sometimes considered as biomass, such as municipal waste—were also considered. The analysis of switchgrass was based on information from a literature review that did not provide adequate or comparable information to what was available from our forest biomass modeling. The switchgrass analyses in this report are incomplete and are included for information and comparative purposes only.

With respect to the forest's low-grade wood resource potentially used for energy, the end products can be solid (cordwood, woodchips, or wood pellets), liquid (pyrolysis oil or cellulosic ethanol), or gas (synthetic or producer gas made through "gasification" and "bio-char" technologies). The end uses can also range from residential to industrial applications, and fall into three general categories: electricity power production, thermal applications for heating or using thermal heat for space cooling in vapor absorption chillers, or emerging technologies such as cellulosic ethanol or gasification. Between the first two end-use categories is combined heat and power (CHP), which can be thermal-led (optimizing heat production with some electricity produced) or electricity-led (sizing the plant for optimal electricity production and using some of the heat).

Some of these technologies and applications are well established and have been in place for years. Others are pre-commercial or still under development. In the sections that follow, we describe two main currently available applications for electricity and CHP. This discussion focuses on those technologies and applications that are already well established, or are technologically achievable in the immediate future should policies wish to guide additional biomass in these directions. These are the applications most likely to place demands on southeastern forest resources in the short term.

Among these application areas, 12 technology pathways were selected to describe how biomass might be used. These pathways are used to evaluate and compare different scenarios for forest management and carbon impacts if policies are directing biomass use toward stand-alone electrical generation, and to enable comparison to the most likely fossil fuel alternatives (out of which four fossil fuel pathways were chosen). The pathways and full data assumptions are displayed in Appendix A.

2.1.1 ELECTRICITY GENERATION

2.1.1.2 Current Sources of Electrical Supply

The seven-state region produced a total of 858,238,084 megawatt hours (MWH) of electricity in 2009, the most recent year for which full data is available (EIA, 2011). Of the total electrical generation in the region, 38 percent is generated by coal power plants (345,882,814 MWH). The second largest electrical source for the region is nuclear power, comprising 29 percent of the total regional generation (248,688,358 MWH). Although natural gas is the largest fuel source for electrical generation in Florida, for the seven-state study region it is the third largest fuel source for electrical generation with 197,687,923 MWH (28 percent of total regional generation). Renewable energy accounts for only 6 percent of electrical generation in the seven-state area, with hydroelectric plants producing 4 percent of the regional electrical generation. The state energy profiles produced by the EIA do not tabulate statistics for biomass electrical generation, which is included in the category of "other renewables" and which accounts for 2 percent of the regional electrical generation.

Tables 12-18 below and on the following pages summarize the state electrical generation profiles for 2009.

Table 12. Virginia Electrical Generation Profile

Total Electric Industry	**70,082,066**
Coal	25,599,288
Petroleum	1,087,660
Natural Gas	12,201,384
Other gases[15]	-
Nuclear	28,212,252
Hydroelectric	1,478,630
Other renewables[16]	2,417,519
Pumped Storage	-1,334,709
Other[17]	420,042

2. TECHNOLOGY PATHWAYS *(cont'd)*

Table 13. North Carolina Electrical Generation Profile	
Total Electric Industry	**118,407,403**
Coal	65,082,782
Petroleum	296,859
Natural Gas	4,851,885
Other gases[15]	-
Nuclear	40,847,711
Hydroelectric	5,171,257
Other renewables[16]	1,893,404
Pumped Storage	43,077
Other[17]	220,428

Table 14. South Carolina Electrical Generation Profile	
Total Electric Industry	**100,125,486**
Coal	34,477,512
Petroleum	523,484
Natural Gas	9,780,193
Other gases[15]	-
Nuclear	52,149,734
Hydroelectric	2,332,005
Other renewables[16]	1,747,971
Pumped Storage	-976,443
Other[17]	91,029

Table 15. Florida Electrical Generation Profile	
Total Electric Industry	**217,952,308**
Coal	54,003,072
Petroleum	9,221,017
Natural Gas	118,322,308
Other gases[15]	6,800
Nuclear	29,117,877
Hydroelectric	208,202
Other renewables[16]	4,340,332
Other[17]	2,732,701

Table 16. Georgia Electrical Generation Profile	
Total Electric Industry	**128,698,376**
Coal	69,478,196
Petroleum	649,674
Natural Gas	20,505,749
Other gases[15]	-
Nuclear	31,682,579
Hydroelectric	3,259,683
Other renewables[16]	2,825,170
Pumped Storage	271,988
Other[17]	25,337

2. TECHNOLOGY PATHWAYS *(cont'd)*

Table 17. Alabama Electrical Generation Profile	
Total Electric Industry	**143,255,556**
Coal	55,608,724
Petroleum	219,274
Natural Gas	31,617,083
Other Gases[15]	134,728
Nuclear	39,716,204
Hydroelectric	12,535,373
Other Renewables[16]	3,049,857
Other[17]	374,314

Table 18. Tennessee Electrical Generation Profile	
Total Electric Industry	**79,716,889**
Coal	41,633,240
Petroleum	186,930
Natural Gas	409,321
Other gases[15]	12,010
Nuclear	26,962,001
Hydroelectric	10,211,962
Other renewables[16]	950,468
Pumped Storage	-649,832
Other[17]	788

2.1.2 CURRENT BIOMASS POWER PLANTS

The region is home to 17 biomass electrical plants. Detailed information is available for 12 of these plants, with a total capacity of 246 megawatts (Oak Ridge National Laboratory, 2011).

Table 19. Current Biomass Power Plants

Plant Name	State Name	Capacity MW	Online Year
Bryant Sugar House	Florida	6.63	1962
Stone Container Florence Mill	South Carolina	7.63	1963
DG Telogia Power	Florida	12.50	1986
Stone Container Hopewell Mill	Virginia	20.35	1980
Jefferson Power LLC	Florida	7.50	1990
Craven County Wood Energy LP	North Carolina	45.00	1990
Port Wentworth	Georgia	21.60	1991
Ridge Generating Station	Florida	47.10	1994
Multitrade of Pittsylvania LP*	Virginia	26.55	1994
Okeelanta Cogeneration	Florida	24.97	1996
Scott Wood	Virginia	0.80	2003
Buckeye Florida	Florida	25.00	2006
	Average Capacity	**20.47**	
	Total Capacity	**245.63**	

** This plant is now owned by Dominion and has a 79 MW capacity. Dominion has announced it will increase its wood requirement to 850,000 green tons/year.*

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.2.0 SUMMARY OF PATHWAYS

Pathways #1-4 describe using woodchip fuel for electrical generation.

Pathway #1 describes the average existing biomass electrical generating facility, with a typical size of 20 MW and a typical efficiency of 26 percent.

Pathway #2 describes a typical new biomass plant as proposed in the region, with a larger plant capacity of 50 MW and a higher efficiency of 28 percent.

Pathway #3 considers co-firing woodchips with coal in existing coal power plants at a balance of 10 percent woodchips and 90 percent coal. Biomass co-firing in existing coal plants would utilize biomass fuels with much lower capital investment than constructing new electrical generating stations designed to burn woodchips.

Pathway #4 considers a CHP application in a 5 MW facility with 75 percent total efficiency.

Pathways #5-7 consider using switchgrass pellets for electrical generation. The pelletization of switchgrass for use in boilers and other combustion systems is still under development. While switchgrass pellets are used in some thermal applications and have been test fired in electrical generating plants, no switchgrass electrical generation exists. Since this option is hypothetical and for the purpose of comparing the carbon implications of different types of biomass fuels, the switchgrass pathways were assumed to have the same capacities as the woodchip-fueled plants with which they are being compared.

Pathway #5 considers a 50 MW plant comparable to the new woodchip electrical generating plants considered in pathway #2.

Pathway #6 considers co-firing 10 percent switchgrass in existing coal plants.

Pathway #7 considers a CHP plant of 5 MW.

The analysis of switchgrass was based on information from a literature review that did not provide adequate or comparable information to what was available from our forest biomass modeling. The switchgrass analyses included in this report are incomplete and are included for information and comparative purposes only.

Pathways #8-10 explore electrical generation with coal.

Pathway #8 considers an average coal plant existing in the region with a capacity of 450 MW (rounded from regional average to nearest 50 MW) and an efficiency of 33 percent.

Pathway #9 considers a larger (600 MW), slightly more efficient (36 percent) coal plant typical of the size and type proposed for new coal plants in the region.

Pathway #10 is a theoretical option considering a coal CHP project similar to the proposed biomass CHP projects in pathways #4 and #7.

Pathway #11 considers a large natural gas electrical plant with an 800 MW capacity and 42 percent efficiency as representative of new natural gas plants proposed for the region.

A 12th scenario, **Pathway 2A**, was also considered as an alternative energy end use for woody biomass. Woody biomass pelletization was considered versus combustion of biomass for power generation. The pellets would most likely be exported to Europe for combustion for either heating or power generation. This scenario considers the additional carbon emissions if the biomass from the southeast region is used to make pellets, and those pellets are exported across the Atlantic to Europe and used to generate power there. Wherever they are burned, the pellets produce 765.9 pounds of CO_2 per MMBtu when combusted for electrical generation. Additional emissions result from the energy consumed in making pellets and for transportation across the Atlantic. 26.74 pounds of CO_2 would be released in the Southeast in the process of pellet production per MMBtu of pellets produced. Another 11.55 pounds of CO_2 would be released in transport from production facility to US ports and from European ports to electrical generation plants. An additional 25.87 pounds of CO_2 per MMBtu of pellets would be emitted in cross-Atlantic transport. In this scenario, some of the carbon emissions involved in pelletization would occur in the Southeast, but a good deal of the carbon emissions would occur in transportation and in Europe when the pellets are combusted.

The carbon emissions from pellet production and transport to the final end use were compared to the emissions from production and transport of woodchips (16.5 pounds per MMBtu of output), switchgrass (16.5 pounds per MMBtu of output), coal (21.3 pounds per MMBtu output), and natural gas (80.4 pounds per MMBtu of output) (Manomet, 2010). These emissions include harvesting or mining, refining and/or other fuel processing, and transport from the site of harvest or collection to processing sites, then to southeastern power plants. The carbon emissions from each fuel source for production and transportation are displayed in Table 24 on page 62.

2.2.1 Electrical Generation Pathways

Table 20 below presents the CO_2 emissions from electrical generation from the nine electrical technology pathways.

Table 20. Electrical Generation Pathway CO_2 Emissions

Electrical Generation Pathway	CO_2 Emissions (lbs/MMBtu output)
Wood (existing plants)	859
Wood (new plants)	783
Wood (exported pellets)	1,010
Coal/wood Co-firing	677
Switchgrass	829
Coal/switchgrass co-firing	669
Coal (existing plants)	643
Coal (new plants)	587
Natural gas	359

Of all the fuels considered, natural gas is the cleanest and the lowest carbon emitting due to its ability to generate power using a direct combustion turbine at higher efficiency than traditional steam turbine technologies, and the fact that it has less carbon per unit of energy.

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.2.2 CHP Options

All electrical production from combustion of fuels creates excess heat that is often wasted. In the case of power plants, excess heat is often simply released as steam from the turbine, condensed, and returned to the boiler. CHP systems seek to utilize some or all of this excess heat. As this excess heat is made into useful energy, the efficiency of the generating system increases with the proportion of heat it uses.

Electricity-led CHP is an option where power production is near a thermal demand. A 20 MW power plant produces enough heat to heat approximately 1,100 homes.[18] To date, however, the economics, incentives, and siting preferences have not resulted in power plants choosing CHP. As a result, regardless of the fuel source producing the electricity, approximately 65-75 percent of the energy value of the fuel in conventional combustion systems has been wasted as lost heat. Taking advantage of this energy value requires planning, intentional siting, and either financial or regulatory incentives that promote power producers deciding to increase the complexity of their systems by the addition of steam or hot water as a salable output. This is not the business model that has been pursued to date. Recently, with the increased appreciation of efficiency and concern about efficient use of resources, biomass power developers are beginning to incorporate some CHP in their proposals, though because of the large amount of heat available relative to potential nearby uses, these projects often make use of only a small percentage of the available heat (10-15 percent).

In contrast, thermally led CHP maximizes the demand for heat, but produces relatively little electricity. At the community scale, a typical CHP facility might produce 1-5 MW of electricity while providing enough steam for process heat and/or cooling for a small industrial park.

An important point to note is that the cost-effective scale of producing electricity alone leads to plants in the 20-50 MW size range. At this scale, it is most cost effective to produce the power, and any CHP component is a complicating factor that tends to reduce the overall cost effectiveness of the project under current policies that subsidize electrical production but do not subsidize or reward thermal energy production. At smaller-scale thermal-led CHP systems of 1-5 MW, the opposite is true—production of heat alone maximizes cost effectiveness of the project, and adding an electrical component reduces the overall economics of the project, i.e., the savings in heat help subsidize the electrical generation components.

Conventional technology requires the production of steam to produce electricity, but European commercial technologies produce electricity without steam production. These technologies include gasification where the produced gas is combusted directly in a combustion turbine, and Organic Rankine Cycle (ORC) thermal-oil technology that uses a thermal oil to gain temperature gradients necessary to produce electricity without steam so that the thermal system can be designed around low-pressure hot water. The ORC system, while more easily incorporated into a hot water-based thermal application and therefore of greater potential in smaller CHP systems (see below), is

still only approximately 20 percent efficient on its own in the production of electricity, but would be expected to be between 75-85 percent efficient in heat-led applications. Heat-led gasification can be expected to be approximately 75 percent efficient.

Pathways #4, #7, and #10 describe moderate-sized CHP systems capable of producing 5.0 MW of electricity. The first uses conventional technology, producing steam to run a turbine, and fully utilizes the 34 MMBtu/hour of heat generated to heat facilities on the order of magnitude of a college campus, a hospital, or small community. As such, the overall efficiency is rated at 75 percent, which is typical for such units. The second pathway uses gasification technology, which is just an emerging technology here in the United States. Still, there is an example of a commercial system operating since 2000 in the Town of Harboøre, Jutland, Denmark that produces 1.6 MW of electricity and heats 900 homes (BERC, 2010). The efficiency rating for this system is also 75 percent.

Table 21 below presents CO_2 emissions from energy conversion for the three CHP pathways considered.

Table 21. CHP Pathway CO_2 Emissions

CHP Pathway	CO_2 Emissions (lbs/MMBtu)
Wood	296
Switchgrass	314
Coal	295

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.3.0 EFFICIENCY

As has been discussed throughout, the efficiency with which energy value is extracted from biomass—or fossil fuel—varies according to the energy product sought and the technology pathway used to make that product. Figure 4 and Table 22 on the following pages show the range of efficiencies for the different applications and pathways selected, from most efficient to least efficient on a gross heat efficiency basis. The electrical efficiency for each option shows the percent of total energy in the fuel source that is converted into electricity. The gross thermal efficiency is the total efficiency for each option, including both the electrical efficiency and any energy captured and used as thermal energy.

It is important to recognize that what is presented is just the efficiency of the process to produce energy or fuel or product from the biomass. This does not include any losses incurred through the use of the end product. For example, for electricity, these efficiencies do not include line losses or the efficiency of a given appliance to turn remaining electricity into useful work. Similarly, for the transportation fuels, this does not include the relative inefficient (18 percent) ability of your car to take the energy value of the fuel and convert it into the work of moving you down the road. Finally, for the thermal applications, it does not include the loss of heat exchange from the thermal system to a home, or the efficiency of a home to retain heat. These examples show that further down the process more losses of the energy value of the original biomass will be incurred. They may be smaller or they may be quite large, depending on the end uses.

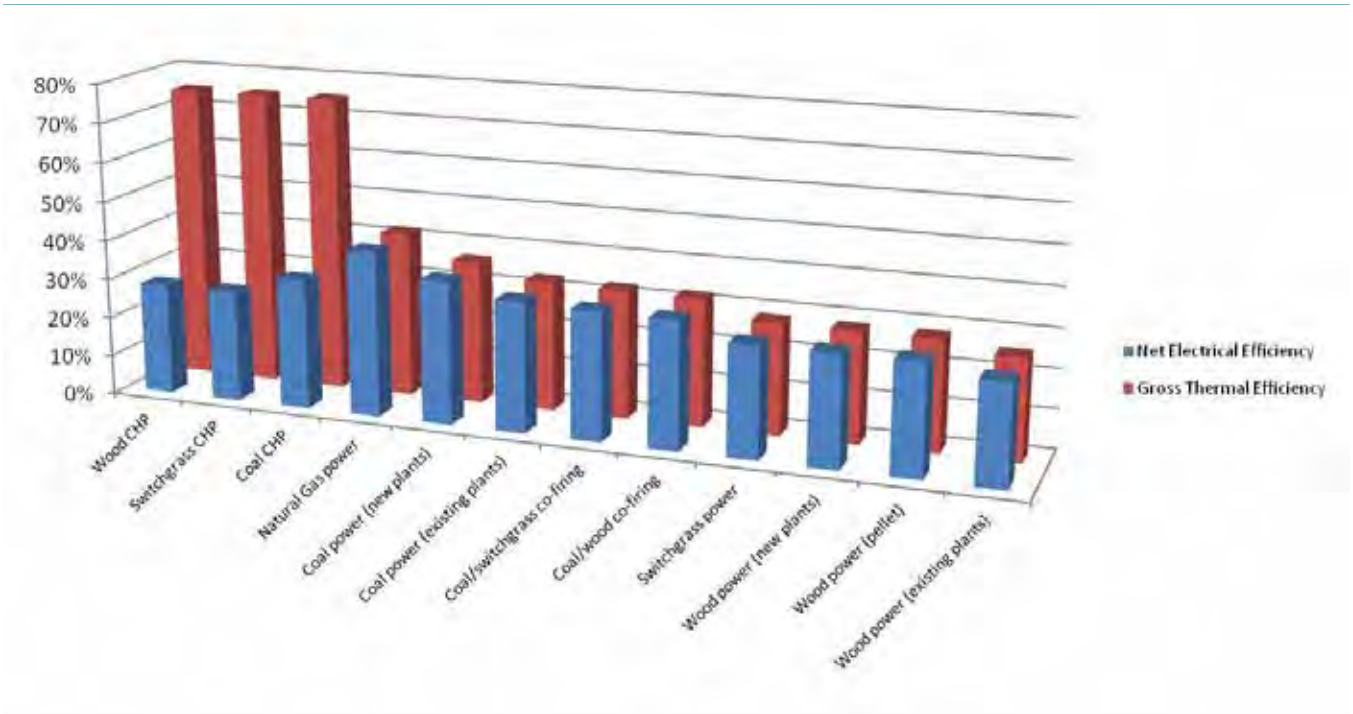


Figure 4.

Graph of Efficiency of 12 Technology Pathway Options.[19]

Table 22. Efficiency of 12 Technology Pathway Options[20]

Technology Pathway	Net Electrical Efficiency	Gross Thermal Efficiency
Wood CHP	28.2%	75.0%
Switchgrass CHP	28.2%	75.0%
Coal CHP	33.0%	75.0%
Natural Gas power	42.0%	42.0%
Coal power (new plants)	36.3%	36.3%
Coal power (existing plants)	33.0%	33.0%
Coal/switchgrass co-firing	32.5%	32.5%
Coal/wood co-firing	32.3%	32.3%
Switchgrass power	28.2%	28.2%
Wood power (new plants)	28.2%	28.2%
Wood power (pellet)	28.2%	28.2%
Wood power (existing plants)	25.6%	25.6%

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.4.0 CARBON IMPACTS

The CO_2 emissions from each of the pathways vary depending on the fuel and the efficiency of the product made. The CO_2 emissions expressed as "input" energy and the CO_2 emissions based on "output" energy reflect the efficiency of the biomass energy conversion. The carbon content on an input basis reflects only the carbon content of the fuel on a pounds per MMBtu of energy content basis before the fuel is combusted. The carbon emissions on an output basis also reflect the efficiency of the energy generation process, and reflect how much carbon has been emitted into the atmosphere after the fuel has been combusted. The input CO_2 emissions are a measure only of the pre-combustion carbon content of the fuel, while the output emissions calculate the total CO_2 emissions once the fuel has been combusted and utilized in a particular manner.

The tables and figures on the following pages reflect the different pathways. The CO_2 emissions from fuel to energy conversion are presented first on an input and output basis, followed by the CO_2 emissions from production and transportation of fuel associated with each pathway on an input and output basis, then the total CO_2 emissions for each pathway on an output basis are compared.

The emissions from production and transportation for the pellet scenario exceed the emissions due to production and transportation from any other fuel type. This is due to the assumption that the pellets will be transported to European markets for final consumption, adding 25.87 pounds of CO_2 per MMBtu of pellets. With very low-heating demands in the climate of the Southeast, however, exporting the pellets would indeed be the most likely scenario unless used for power production domestically.

As with the efficiency discussion, it is very important to note that the following tables and figures do not reflect a life-cycle analysis of these technology pathways, merely the carbon emissions resulting from the fuel-to-energy conversion and the emissions from production and transportation. While full carbon life-cycle accounting for all pathways is beyond the scope of this report, life-cycle estimates of carbon emissions for the technological options considered in Chapter 3 are provided there.

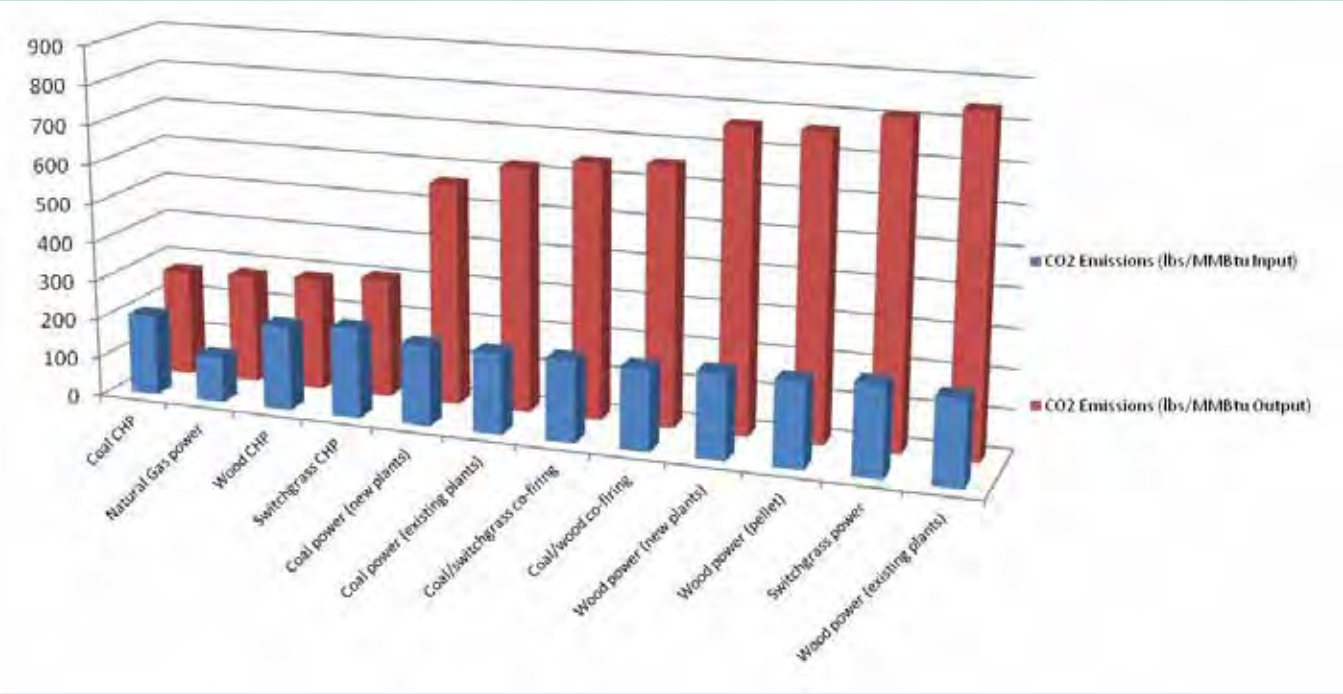


Figure 5.

Graph of CO_2 Emissions from Energy Conversion of 12 Technology Pathways.[21]

Table 23. CO_2 Emissions from Energy Conversion of 12 Technology Pathways[22]

Technology Pathway	CO_2 Emissions (lbs/MMBtu Input)	CO_2 Emissions (lbs/MMBtu Output)
Coal CHP	205.3	273.7
Natural Gas power	117.0	278.6
Wood CHP	215.7	287.6
Switchgrass CHP	229.2	305.6
Coal power (new plants)	205.3	565.6
Coal power (existing plants)	205.3	622.1
Coal/switchgrass co-firing	207.7	648.4
Coal/wood co-firing	206.3	656.3
Wood power (new plants)	215.7	765.9
Wood power (pellet)	215.7	765.9
Switchgrass power	229.2	812.6
Wood power (existing plants)	215.7	842.5

2. TECHNOLOGY PATHWAYS *(cont'd)*

Figure 6.

Graph of CO_2 Emissions from Fuel Production and Transportation of 12 Technology Pathways[23]

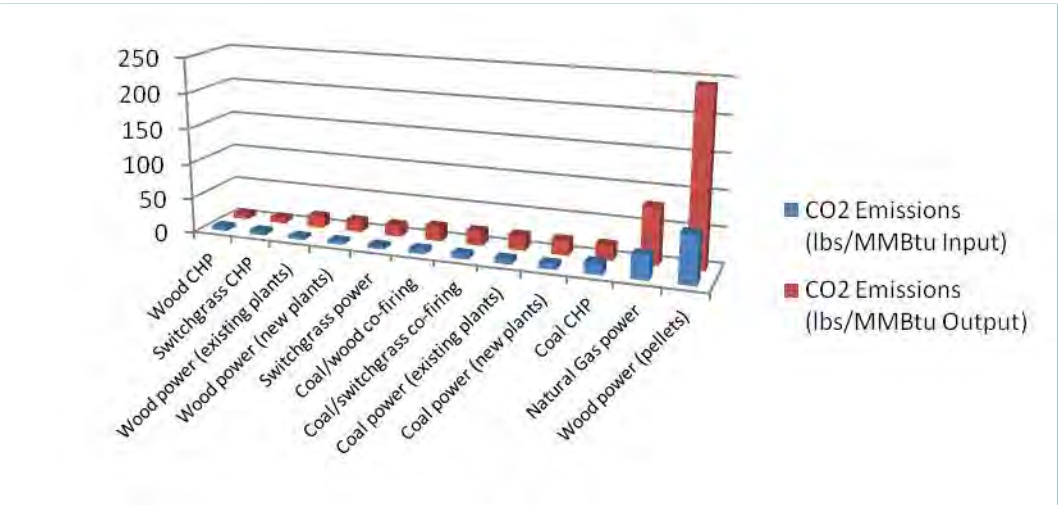


Table 24. CO_2 Emissions from Fuel Production and Transportation of 12 Technology Pathways[2]

Technology Pathway	CO_2 Emissions (lbs/MMBtu Input)	CO_2 Emissions (lbs/MMBtu Output)
Wood CHP	6.1	8.1
Switchgrass CHP	6.1	8.1
Wood power (existing plants)	4.2	16.5
Wood power (new plants)	4.7	16.5
Switchgrass power	4.7	16.5
Coal/wood co-firing	6.6	20.8
Coal/switchgrass co-firing	6.7	20.8
Coal power (existing plants)	7.0	21.3
Coal power (new plants)	7.7	21.3
Coal CHP	16.0	21.3
Natural Gas power	33.8	80.4
Wood power (pellets)	68.8	244.4

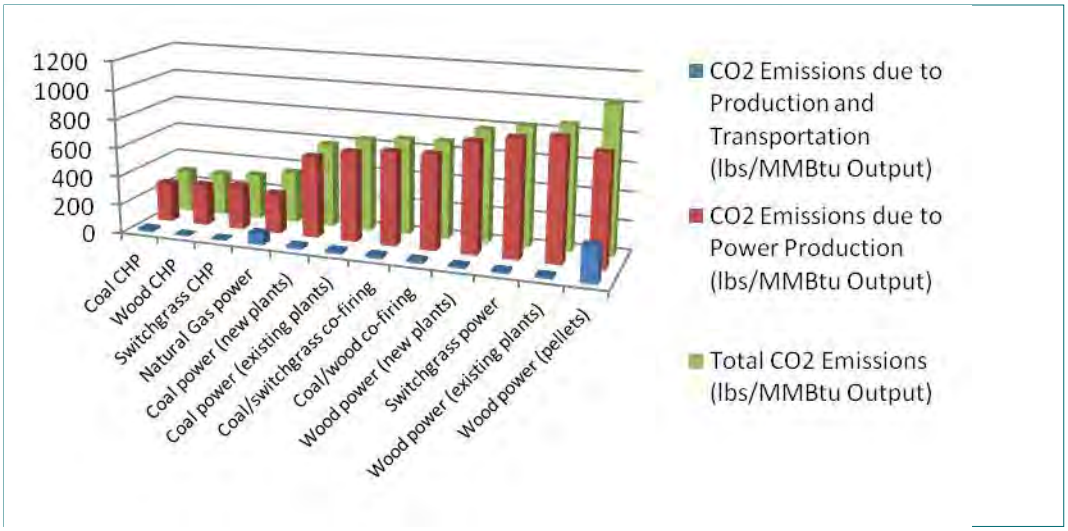


Figure 7.

Graph of Total CO_2 Emissions on Energy Output Basis of 12 Technology Pathways[25]

Table 25 . Total CO_2 Emissions on Energy Output Basis of 12 Technology Pathways[26]

Technology Pathway	CO_2 Emissions due to Production and Transportation (lbs/MMBtu Output)	CO_2 Emissions due to Power Production (lbs/MMBtu Output)	Total CO_2 Emissions (lbs/MMBtu Output)
Coal CHP	21.3	273.7	295.0
Wood CHP	8.1	287.6	295.6
Switchgrass CHP	8.1	305.6	313.6
Natural Gas power	80.4	278.6	359.0
Coal power (new plants)	21.3	565.6	586.8
Coal power (existing plants)	21.3	622.1	643.4
Coal/switchgrass co-firing	20.8	648.4	669.2
Coal/wood co-firing	20.8	656.3	677.1
Wood power (new plants)	16.5	765.9	782.5
Switchgrass power	16.5	812.6	829.2
Wood power (existing plants)	16.5	842.5	859.1
Wood power (pellets)	244.4	765.9	1010.3

2. TECHNOLOGY PATHWAYS *(cont'd)*

2.5.0 N_2O IMPACTS

Nitrous oxide (N_2O) is a greenhouse gas with an atmospheric lifetime of approximately 120 years. Nitrous oxide is about 310 times more effective in trapping heat in the atmosphere than CO_2 over a 100-year period (EPA, 2011). EPA also reports that in 2009, 25 percent of total N_2O emissions in the United States came from fossil fuel combustion. There are currently no state or federal regulations regarding N_2O emissions. For the fuel types and energy conversion processes studies, the N_2O emissions, even on a CO_2 -equivalent basis, were insignificant compared to the CO_2 emissions.

Like the carbon emissions just mentioned, the N_2O emissions from each of the pathways vary depending on the fuel and the efficiency of the product made. Generally, the N_2O emissions expressed as "input" energy reflect the fuel the process is based on, and the N_2O emissions based on "output" energy reflect the efficiency of the product conversion, be that electricity, thermal, or fuel. Unlike the carbon accounting, the N_2O emissions calculations do not include the additional N_2O emissions from production and transport of fuels, only the energy conversion of each fuel in each pathway.

As with the efficiency and carbon discussions, it is very important to note this is not a life-cycle analysis of these technology pathways.

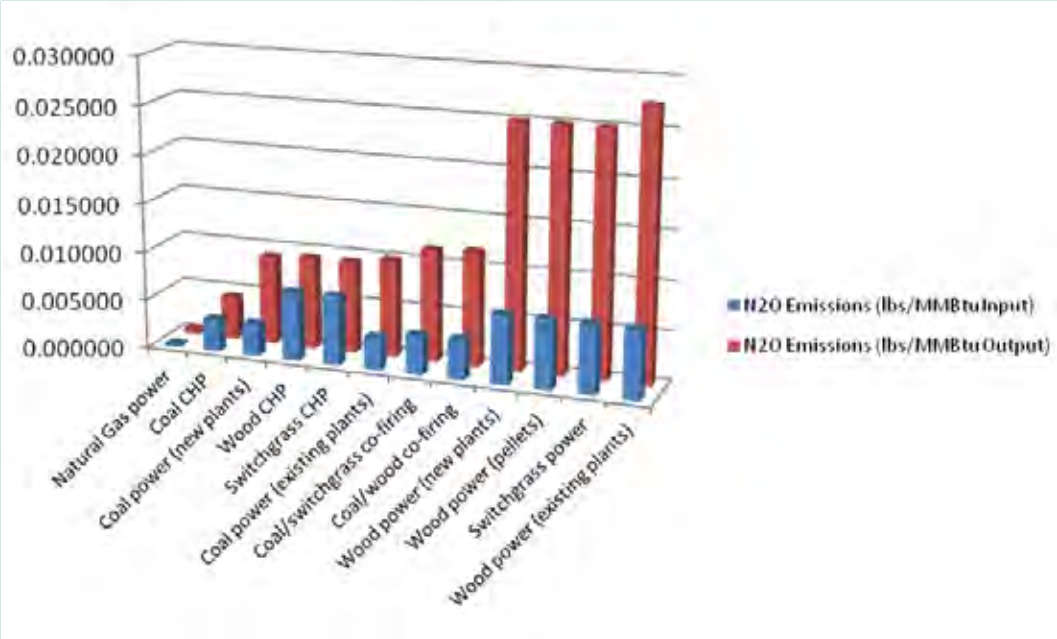


Figure 8.

Graph of N_2O Emissions of 12 Technology Pathways.[27]

Table 26. N_2O Emissions of 12 Technology Pathways[28]

Technology Pathway	N2O Emissions (lbs/MMBtu Input)	N2O Emissions (lbs/MMBtu Output)	Output N2O Emissions as Tons of CO2 Equivalent
Natural Gas power	0.000220	0.00052	0.0001
Coal CHP	0.003306	0.00441	0.001
Coal power (new plants)	0.003306	0.00911	0.001
Wood CHP	0.007054	0.00941	0.001
Switchgrass CHP	0.007054	0.00941	0.001
Coal power (existing plants)	0.003306	0.01002	0.002
Coal/switchgrass co-firing	0.004056	0.01150	0.002
Coal/wood co-firing	0.004056	0.01171	0.003
Wood power (new plants)	0.007054	0.02505	0.003
Wood power (pellets)	0.007054	0.02505	0.003
Switchgrass power	0.007054	0.02505	0.003
Wood power (existing plants)	0.007054	0.02755	0.004

3. ATMOSPHERIC CARBON ANALYSIS

3.1.0 SUMMARY

Spatial Informatics Group has provided an atmospheric carbon-balance analysis of biomass feedstock for this study. This analysis was conducted for biomass stand-alone electric power and electric-led CHP applications. Thermal energy pathways, which have significantly different life-cycle carbon due to higher efficiencies, were not considered in this analysis. We produced an analysis of existing and proposed biomass electric power facilities in the context of a forested landscape. The study area encompassed more than 88 million acres over seven states.

This study used carbon accounting principles that are consistent with accepted forest carbon protocols to examine the consequences of atmospheric carbon balance relative to a baseline that is geographically constrained to the affected area.

Our findings indicate that in the current situation, 17 biomass electric facilities generate 159 megawatts and pellet manufacturers produce 1,775,000 tons of pellets. The megawatts are generated here in the United States and the pellets are manufactured here with some shipped to domestic plants but most bound for Europe. The facilities we examined were producing improved atmospheric carbon balance relative to using other energy fuels and technologies to provide equivalent power at a landscape scale. We modeled an additional 22 biomass power facilities that would generate 1,014 MW of electricity and pellet plants that produce 3,050,000 tons of pellets (mostly shipped to Europe) to represent the proposed expansion (as of May 2011) of the biomass electric-generating sector in the Southeast in the next several years.

These additional biomass facilities were also favorable relative to the alternatives, in the long term, because of the sustained production of wood fiber, assuming all stands are replanted or naturally regenerated to achieve full restocking, and no forest land conversion. A carbon debt period of 35-50 years, however, was required for woody biomass to achieve a beneficial atmospheric carbon profile relative to the other pathways examined at a landscape scale.

This multi-decade carbon debt period is consistent with other studies (Manomet 2010, McKechnie 2011) that have used life-cycle analysis, forest carbon accounting, and a "business-as-usual" baseline to compare biomass to other forms of energy production. The Manomet modeling produced a 42-year payback period for biomass versus coal-generated electricity, and the McKechnie modeling indicated 17-38 year payback periods for generating electricity with biomass instead of coal. Although these patterns are basically consistent, the actual differences in debt periods are expected in different forest types and harvest scenarios. In addition, our model includes a more precise modeling of actual harvesting methods in real stands distributed across the landscape and linked to specific facilities. There are significant differences in the payback periods required to re-sequester all the emitted carbon and return to what may be termed a "carbon-neutral" situation. Our modeling indicates a 53-year time period while the Manomet results for Massachusetts indicate more than 100 years are required.

Assumptions regarding the required biomass supply per unit of power produced an effect on the atmospheric carbon balance for the build-out of the proposed facilities. A higher figure for biomass per unit of power produced showed that the number of years was extended before biomass was shown to be better than fossil fuels.

Naturally regenerated hardwood forest types were also shown to store as much or more carbon on a per-acre basis than most other forest types and plantations, even when regularly harvested for biomass in integrated sawtimber and pulpwood harvests. Tradeoffs between utilizing pulpwood and residuals for biomass energy were found to be most appropriately addressed at project- or stand-level scales.

This study suggests that the atmospheric carbon balance of biomass electric power is better in the long term relative to fossil fuel pathways. A period of decades is required, however, to achieve this result due to the changes in the stored carbon on the landscape relative to a baseline. As biomass demand increases with more facilities beyond the 22 currently proposed, the ability of the forested landscape to provide biomass supply and store carbon may become more limited, particularly in localized areas with strong demand. As this occurs, other factors may become more important in determining the atmospheric carbon balance of biomass energy such as the extent to which biomass demand drives new forest conversion or diversion of wood from other existing uses.

3.2.0 INTRODUCTION

One of the major tasks of this study is to provide a landscape life-cycle analysis of three major feedstocks under two likely scenarios for biomass electric power and electric-led CHP.

This chapter addresses the landscape carbon life-cycle analysis. It provides a section on introduction, methods, and findings. Technical details are presented in the appendix. An executive summary that addresses the full scope of the project that integrates all the tasks is also provided. Eight specific questions were posed to the research team for analysis:

1. What are the GHG consequences of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?
2. What are the GHG consequences of operating the existing biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants?
3. What are the GHG consequences of varying the amounts of biomass required to make a specific amount of electricity?
4. What are the GHG consequences of using forest-derived biomass versus non forest-derived biomass?
5. What are the GHG consequences of using tops and limbs (residuals) for biomass supply versus pulpwood (main stems)?
6. What are the GHG consequences of using natural stands versus plantations to fuel an expansion of biomass electric power in the Southeast?
7. What are the GHG consequences of varying levels of pellet export to Europe for electric power generation from the Southeast?
8. Is there enough biomass available to supply 22 new biomass facilities while limiting the amount of residuals that can be removed to protect forest health?

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.0 METHODOLOGY

This analysis examined the GHG implications of biomass electric generation scenarios for a study area in the southeastern United States. The study area included four eco-sections representing a large portion of the Southeast (see Figure 9 on the opposite page). The study was restricted to these eco-sections to keep the analysis workload reasonable while allowing a large and representative portion of the region to be studied. The following discusses the facilities studied, technology pathways considered, forest growth simulations, and carbon-accounting simulations.

To understand the GHG implications of increased demand, we examined 17 existing facilities and the addition of 22 new biomass electric power facilities to represent the proposed expansion of the biomass electric sector in the Southeast. In order to inform the question of GHG impacts of biomass energy, we examined the GHG implications of the emissions associated with burning biomass feedstock from the forest in relation to other sources of fuel and technology pathways. We also conducted sensitivity analyses on a number of factors to understand how the GHG accounting might be affected.

The atmospheric carbon analysis was divided into specific sub-tasks that were used to produce the work in this report. The sub-tasks are described in the following sections with detailed information provided in the appendix. Below is a list of the sub-tasks:

- Sub-Task 1. Geospatial Analysis
- Sub-Task 2. Definition of Silvicultural Prescriptions for Eco-Regions, Forest Types, and Stand Origin
- Sub-Task 3. Inventory Data Preparation
- Sub-Task 4. Forest Modeling
- Sub-Task 5. Carbon Accounting
- Sub-Task 6. Definition of Landscape and Facilities-Modeling Framework
- Sub-Task 7. Integration of Geospatial and Attribute Data
- Sub-Task 8. Carbon Landscape Analysis
- Sub-Task 9. Sensitivity Analysis
- Sub-Task 10. Draft Final Report
- Sub-Task 11. Final Report

3.3.1 Geospatial Analysis

The purpose of this task was to generate spatial data that allowed the study to be conducted at the landscape level using an integrated all-lands approach. This analysis produced information that reflected the realities of the landscape as they exist today with no assumptions made about land-use change or changing market dynamics. This task quantified vegetation type, transportation distances, constraints on forest management, and operational restrictions as they currently exist in the region. What follows is a summary.

Vegetation Type

There were four eco-sections used for analysis, which may be found in Description of Ecological Subregions: Sections of the Conterminous United States (McNab et al., 2005). Figure 9 on the next page shows the location of these eco-sections with the major forest types. Table 27 on the next page shows the acres estimated from the Forest Inventory and Analysis (FIA) databases for each eco-section and forest-type group.

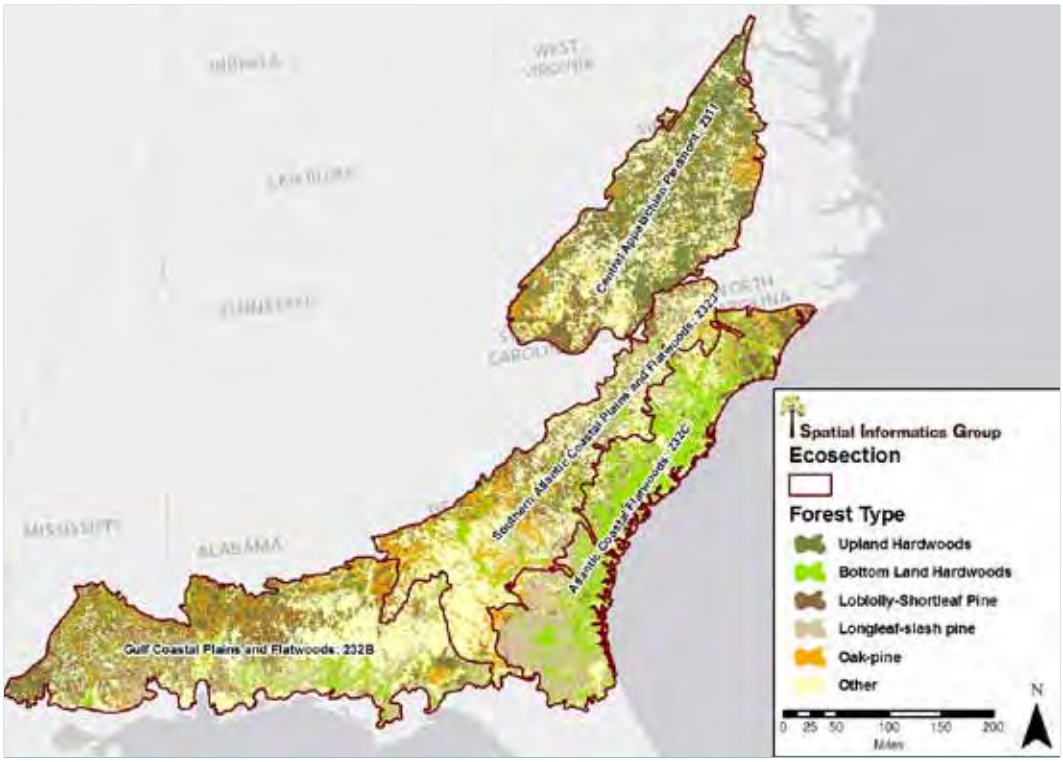


Figure 9.

Map of eco-sections and forest types within the study area. The study area was composed of the four eco-sections shown.

Table 27. Acres by Forest-Type Group, Stand Origin, and Eco-Section

Forest-Type Group	2311-Central Appalachian Piedmont	232B-Gulf Coastal Plains and Flatwoods	232C-Atlantic Coastal Flatwoods	232J-Southern Atlantic Coastal Plains and Flatwoods
Bottomland Hardwoods	629,766	2,735,943	3,118,925	2,418,890
Loblolly/Shortleaf Natural	1,431,249	2,086,954	1,371,449	1,374,118
Loblolly/Shortleaf Plantation	1,748,837	4,574,524	2,459,067	2,673,421
Longleaf/Slash Natural	4,349	928,478	513,542	695,605
Longleaf/Slash Plantation	260	1,124,209	1,835,337	1,061,007
Upland Hardwood-Oak Hickory	5,832,079	3,866,263	1,025,381	2,257,467
Mixed Pine-Oak Natural	1,350,490	1,754,184	1,002,367	1,182,812
Mixed Pine-Oak Plantation	215,802	610,307	260,002	248,034

Source: FIA (2011)

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Section 231I-Central Appalachian Piedmont. This section is east of the Blue Ridge Mountains in central Virginia and North Carolina. It belongs to the Southeastern Mixed Forest Province (231), which "has generally uniform climate with mild winters and hot, humid summers. Annual precipitation is evenly distributed, but a brief period of mild-to-late summer drought occurs in most years." It has high and low hills with deep weathered soils. Forest vegetation is loblolly-shortleaf pine and oak-hickory types. The Central Appalachian Piedmont section is 32,806 square miles.

Section 232B-Gulf Coastal Plains and Flatwoods. This section extends along the Gulf of Mexico coast from southwestern Georgia and the Florida panhandle west through southern Alabama and ending in southern Louisiana. It belongs to the Outer Coastal Plain Mixed Forest Province (232), which "is an eco-region of humid, maritime climate; winters are mild and summers are warm. Precipitation is abundant with rare periods of summer drought. Upland forest vegetation is dominated by conifers, with deciduous hardwoods along major floodplains." It has a flat weakly dissected landscape of irregular or smooth plains. Vegetation is mainly longleaf-slash pine, loblolly-shortleaf pine, and oak-hickory cover types with oak-gum-cypress along rivers. The Gulf Coastal Plains and Flatwoods section is 43,495 square miles.

Section 232C-Atlantic Coastal Flatwoods. This section extends along the Atlantic coast from southern North Carolina south through South Carolina and Georgia into the northeastern part of Florida. This section belongs to the Outer Coastal Plain Mixed Forest Province (232), which "is an eco-region of humid, maritime climate; winters are mild and summers are warm. Precipitation is abundant with rare periods of summer drought. Upland forest vegetation is dominated by conifers, with deciduous hardwoods along major floodplains." It is a weakly dissected flat alluvial plain. Vegetation is mainly longleaf-slash pine and loblolly-shortleaf pine, with oak-gum-cypress along rivers. The Atlantic Coastal Flatwoods section is 30,215 square miles.

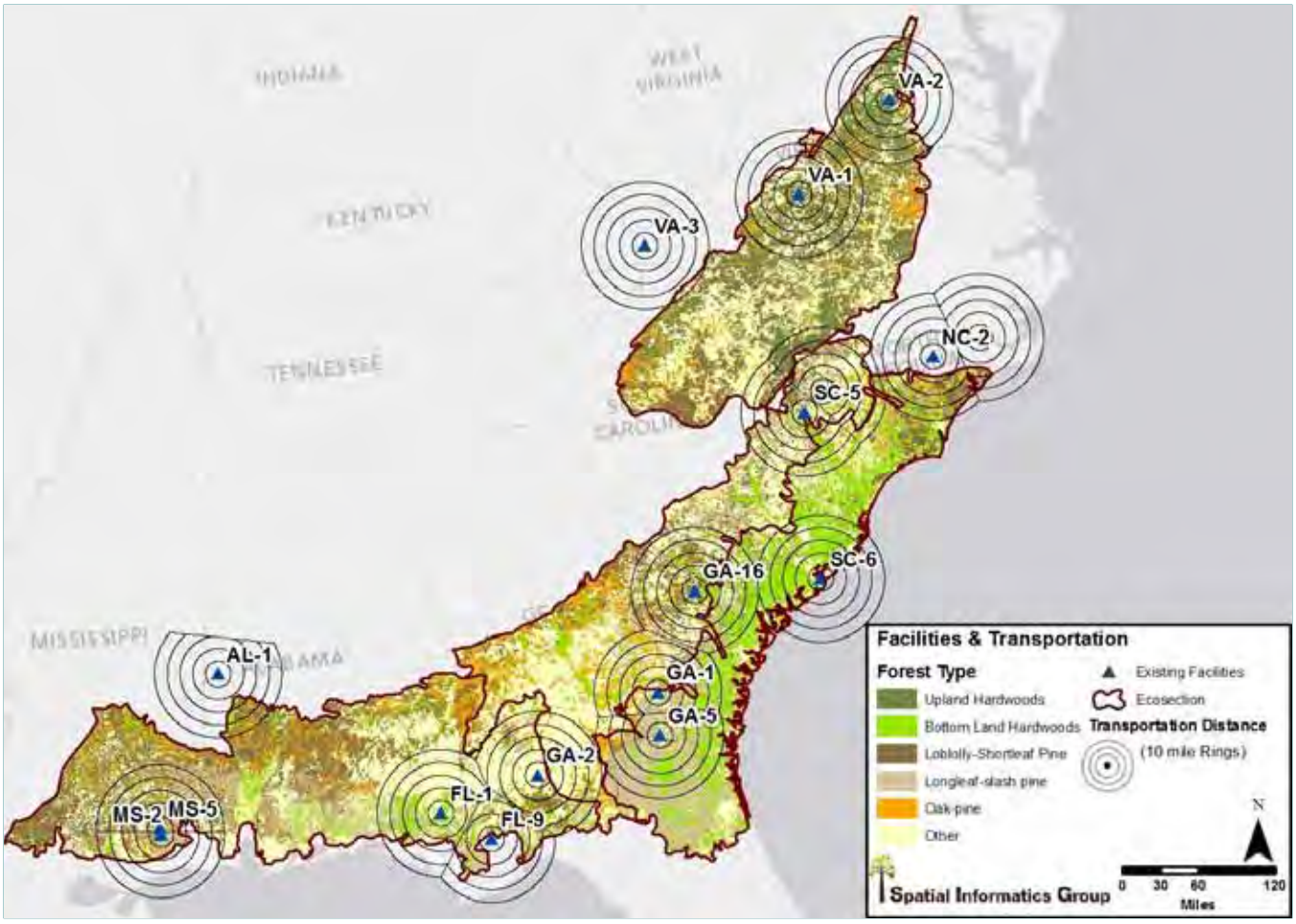
Section 232J-Southern Atlantic Coastal Plains and Flatwoods. This section extends from southern Georgia northeast through central South Carolina and south-central North Carolina. It belongs to the Outer Coastal Plain Mixed Forest Province (232), which "is an eco-region of humid, maritime climate; winters are mild and summers are warm. Precipitation is abundant with rare periods of summer drought. Upland forest vegetation is dominated by conifers, with deciduous hardwoods along major floodplains." This section is weakly dissected irregular or smooth plains. Vegetation is mainly a mixture of loblolly-shortleaf pine, longleaf-slash pine, oak-pine, and oak-gum-cypress cover types. The Southern Atlantic Coastal Plains and Flatwoods section is 31,802 square miles.

Transportation Distance

Existing and proposed facilities data was assembled by the Southern Environmental Law Center (SELC). In order to quantify the biomass supply and transportation emissions to facilities, five concentric transportation rings of 10 miles radius from each facility were constructed. This was done for existing and for existing plus proposed facilities (Figure 10, Figure 11). Wood supply for facilities was modeled using distance to the facilities with equal weight given to each; in other words the distance was equally split between them. Therefore, up to a 50-mile radius was allowed for the wood supply area for a facility unless restricted by neighboring facilities. While this study relies on individual facility data, no attempt was made to characterize the individual facilities, only the aggregate data.

Figure 10.

Existing facilities (17) with transportation rings, showing study area and forest types.



3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

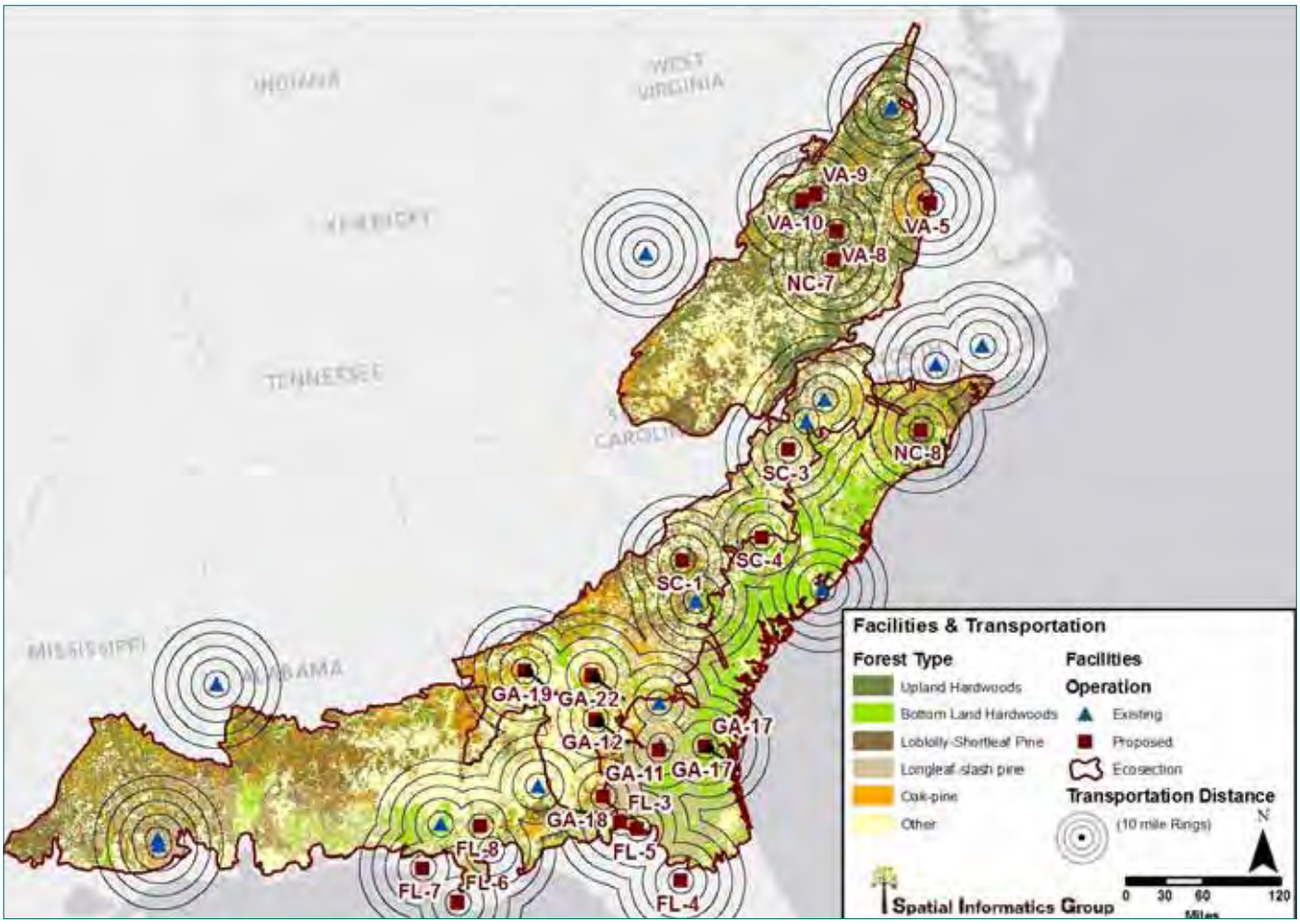


Figure 11.

Existing (17) and proposed (22) facilities with transportation rings, showing study area and forest types. (Some of the points overlap with one another).

Constraints on Forest Management

In order to estimate forest management response to biomass markets so that feedstock supply and subsequent carbon accounting could also be estimated, we identified constraints on forest management applied to private lands in the study area. We considered family forest landowners that would not harvest based on typical economic incentives and physical constraints of the terrain to operations.

The National Woodland Owner's survey results (Butler, 2008) were used to estimate the proportion of the private forested landowners in the study area that would not generally respond to a market by harvesting their lands. Family forests make up 67.4 percent of the private forests and 31 percent do not have a history of harvesting their lands. Therefore we estimate that 20.9 percent of the private forest landscape is in a no-harvest scenario.

Operational Restrictions

Operational acres were those with willing landowner participants and unrestricted access. The acreage required to meet a facilities biomass fiber demand was calculated. The acres remaining after consideration of biomass supply, reserve acres and operationally restricted acres was allocated to the business as usual (BAU). Biomass supply acres were assigned silvicultural prescriptions that incorporated biomass harvesting and BAU acres were assigned baseline silvicultural prescriptions. These prescriptions were assigned by forest-type group so that the appropriate starting inventory was used. Operational restrictions were estimated using FIA data by eco-section and forest-type group (Table 28 below). Restricted acres were defined as those with the following attributes:

- Broken terrain
- Mixed wet and dry soils
- Slopes greater than 40 percent, or
- Water year-round

Table 28. Percent of Operational-Restricted Acres by Eco-Section and Forest-Type Group

Eco-Section	Forest-Type Group	Percent Restricted
231I	Bottom Land Hardwoods	19.5
231I	Upland Hardwoods	3.7
231I	Oak-pine	1.5
231I	Loblolly-shortleaf pine	0.8
232B	Bottom Land Hardwoods	19.6
232B	Upland Hardwoods	2.2
232B	Oak-pine	2.0
232B	Loblolly-shortleaf pine	0.6
232B	Longleaf-slash pine	1.0
232C	Bottom Land Hardwoods	1.0
232C	Upland Hardwoods	1.1
232C	Oak-pine	6.9
232C	Loblolly-shortleaf pine	0.9
232C	Longleaf-slash pine	1.0
232J	Bottom Land Hardwoods	10.7
232J	Upland Hardwoods	1.6
232J	Oak-pine	3.6
232J	Loblolly-shortleaf pine	1.3
232J	Longleaf-slash pine	0.4

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.2 Definition of Silvicultural Prescriptions for Eco-regions, Forest Types, and Stand Origin

The purpose of this sub-task was to define a BAU baseline for silvicultural practices as they exist today from current on-the-ground activity along with a viable biomass alternative. These silvicultural prescriptions were to be assessed by eco-regions, forest type, stand origin, and ownership type. The Forest Guild took the lead in developing these options based on its extensive in-field networks and sustainable silvicultural expertise.

The Forest Guild set up a local forester input process that assisted with defining the BAU- and biomass-affected silvicultural methods used for the forest types and eco-sections considered in this study. The silvicultural simulations by forest type and eco-section are listed in Tables B-1 to B-3 in Appendix B. Note that prescriptions repeat over time. Also in Appendix B, Table B-4 shows the age distribution for one eco-section, for illustration. A set of no-harvest scenarios was also simulated for each eco-section, stand-origin, and site-class category.

Site productivity was grouped into low and high using the FIA site classes: 1-3 were high and 4-7 were low. Three general prescriptions were modeled:

- Baseline, with a biomass market and with no harvesting
- Baseline harvests cut trees down to 4 inches dbh
- Biomass harvests took trees down to 0 inches dbh

Regeneration harvests may have site preparation and burning simulated. Default Forest Vegetation Simulator, Southern Variant (FVS-SN) values were used for naturally regenerated stands except for longleaf pine, which was broadcast burned. Plantations were 100 percent site prepared. The FVS-SN default values were 20 percent treated mechanically, 5 percent burned, and 75 percent untreated. No differences were assumed in site preparation and burning for the baseline versus the biomass harvests.

These simulations represent plausible depictions and are intended to provide data for comparisons between treatments and fiber utilization scenarios. They are not intended to provide predictions of landscape changes over time, which would require a regional timber supply model.

3.3.3 Inventory Data Preparation

The purpose of this sub-task was to prepare the FIA data for analysis. Two elements need to be investigated when preparing FIA data for analysis—data quality and the issue of regeneration.

Data Quality

The FIA data were extracted from eight state-level databases using the *FiaToFvs utility* (Keyser, 2011), which created FVS-formatted databases. These databases were filtered and combined into four databases corresponding to the four eco-sections. FIA plots, which are 4-plot clusters, were treated as stands composed of four plots. The most recent measurement cycle was used for characterizing current conditions. The previous inventory cycle was used in conjunction with the other data for the growth model evaluation. A common starting year of 2010 was used regardless of the actual measurement year of the plot. The most recent (2010) FIA survey summary was used and relative plot weights were retained. In some cases, age was missing from the FIA plots. Since age was used as a trigger for some silvicultural treatments, random ages were assigned to stands where this occurred.

Each set of plots that were projected under a silvicultural scenario were averaged using the FIA expansion factors. This produced a yield stream that reflected the application of the prescription to the average landscape for a particular eco-section, forest-type group, and site group. The two site groups were then averaged together using their relative representation on the landscape. This averaged yield stream was then used in conjunction with vegetation maps to model carbon dynamics.

Regeneration

Regeneration assumptions are important to long-term forest growth projections. Plantation densities (TPA) were based on expert opinion. Natural stand regeneration was based on FIA data queries. Tables B-5 to B-6 in Appendix B show the regeneration assumptions for two examples of forest types for an eco-section. Data in these tables were derived from FIA plots in trees 0-5 inches dbh. Sprouting species automatically sprout when harvested in FVS-SN, so only non-sprouting species were regenerated from seedlings. Regeneration was input 10 years after harvest, at the sapling/pole stage. Sprouting was set to the following to avoid overstocking the stands, which was observed from the simulations using the defaults.

- If stand density index (SDI) less than 100, use 100 percent of default sprouting model
- If SDI 100 to 200, use 90 percent of default sprouting model
- If SDI 200 to 300, use 80 percent of default sprouting model
- If SDI more than 300, use 70 percent of default sprouting model
- If the quadratic mean diameter (QMD) less than 10 (young stands), use 10 percent of default sprouting model (for pre-commercial thinning)
- If the QMD less than 10 and more than 700 trees per acre, use 1 percent of default sprouting model

This appeared to create a generally stable stocking situation over the simulation period. The no-harvest scenarios did not have regeneration modeled.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.4 Forest Modeling

This sub-task focused on quantifying forest biomass dynamics using the above information and standard modeling approaches. Several elements were selected for this analysis, including the data and software used, specifics concerning the growth and yield models, and approaches to evaluating growth. In general, non-merchantable wood (*residuals*) was considered as the first lowest cost supply material, up to the amounts allowed under the sensitivity analysis described below. Clean woodchips from fiber defined as meeting pulp merchantability standards (*pulpwood*) was provided next, also up to the amounts allowed by the sensitivity analysis below. These elements are discussed in detail as follows.

Data and Software

The FIA data (FIA, 2010) was used to develop stand-level data for simulating growth, harvest, and mortality. Eco-section summaries were also queried from the FIA data.

The FVS-SN (version 2/16/2011)(Keyser, 2010), was used for modeling stands. Pine plantations were evaluated using simulations in PTAEDA version 4 (Burkhart et al., 2008), a loblolly-pine plantation model. SUPPOSE (Crookston, 1997) was used for FVS simulations. R statistical software was used for some analysis and graphics (R, 2011). Microsoft Excel was used for data checking, calculations, and graphics. Microsoft Access was used for plot and tree-data storage as well as carbon outputs, which were linked to SUPPOSE software using the database extension (Crookston et al., 2011). The Fia2Fvs utility, available on the FVS website, was used to translate FIA data to an FVS readable Access database.

Growth and Yield Modeling

Non-renewable fuels such as oil, natural gas, and coal do not currently have an operational and economical sequestration component. Forests do naturally remove carbon from the atmosphere, however, and a complete GHG accounting of biomass energy should account for this fact. We considered only private lands for our analysis, which produce 96 percent of the roundwood in the Southeast (Johnson et al., 2009). We modeled forest growth, harvest, and mortality over a 100-year period to understand the long-term GHG implications of supplying biomass.

Each of the five major forest-type groups (Table 27 on page 69) in each of the four eco-sections was modeled under a BAU baseline, with a biomass market and unharvested. This allowed us to construct landscape scenarios that matched generalized landowner responses to available markets. The FIA data (FIA, 2010) were used for the starting conditions.

Figure 12.

Geographic range for the southern variant of FVS. From Keyser (2010).

The FIA databases for each state in our study area were downloaded from the FIA website. Data were queried from the databases to create tree lists for growth simulation. Tree-list queries were constructed for private lands by age, site productivity, stocking, eco-section, and forest type. Within each category, a random sample of plots was taken for the purposes of modeling. At least 250 plots were modeled for each category, when available, so that landscape variation was represented without unnecessary redundancy in data. Regional forest-characterization queries were conducted to ensure FIA data matched with GIS vegetation coverages.

Age class distributions were examined, by category, to characterize starting conditions. Where ages were missing, they were randomly allocated since age was a parameter used for some silvicultural treatments.

FVS-SN (Figure 12 above) was used to model all simulations for 100 years in 5-year increments. Harvests in the no-biomass-harvest baseline scenarios assumed that all non-merchantable wood fiber was left in the woods. Harvests in the biomass scenarios assumed that a minimum of 10 percent of the non-merchantable wood fiber was left in the woods; this assumption allows for 10 percent being a minimum so that between 10-100 percent of non-merchantable wood fiber may be allocated to biomass pools. This amount was varied for the sensitivity analysis.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

The merchantability standards used were the FVS-SN defaults shown in Table 29 below. Other default specifications used in modeling are shown in Table 30 at the bottom of the page. A minimum harvest level of 1,000 cubic feet per acre of merchantable wood fiber was specified for commercial thins, to avoid un-economical harvest simulations.

Table 29. Merchantability Standards from FVS-SN

Pulpwood Volume Specifications		
Minimum DBH/Top Diameter Inside Bark	**Hardwoods**	**Softwoods**
All locations codes	4.0 / 4.0 inches	1.0 / 1.0 inches
Stump Height	**1.0 foot**	**1.0 foot**
Sawtimber Volume Specifications		
Minimum DBH/Top Diameter Inside Bark	**Hardwoods**	**Softwoods**
All location codes	12.0 / 9.0 inches	10.0 / 7.0 inches
Stump Height	**1.0 foot**	**1.0 foot**

Source: Keyser (2010)

Table 30. Default Parameters Used in FVS-SN

	Eco-Section			
Parameter	**Central Appalachian Piedmont (231I)**	**Atlantic Coastal Flatwoods (232C)**	**Southern Atlantic Coastal Plains and Flatwoods (232J)**	**Gulf Coastal Plains and Flatwoods (232B)**
Location Code	81110	81201	81201	80103
Ecol. Unit Code (EUC)	232BIC	232CA	232JA	232BI

Carbon storage from onsite forest pools and long-term storage in wood products and landfills was estimated. Production from residual fiber and wood meeting pulpwood merchantable standards was estimated. The yield streams were annualized to match the demand units for the facilities.

The yields from each forest type were averaged across natural and plantation origin based on the relative abundance of each in each eco-section (see Table 31 below). Harvest of non-merchantable wood was set to a maximum removal of 90 percent for biomass harvesting.

Table 31. Acres of Plantations by Eco-Sections and Forest Type Groups

Eco-Section	Forest Type	Acres	Acres in Plantation	Percent in Plantation
231I	Loblolly-shortleaf pine	4,946,320	2,720,149	55.0%
232B	Loblolly-shortleaf pine	6,810,148	4,082,053	59.9%
232B	Longleaf-slash pine	4,608,327	2,222,395	48.2%
232B	Oak-pine	2,900,973	568,323	19.6%
232C	Loblolly-shortleaf pine	1,891,406	1,047,443	55.4%
232C	Longleaf-slash pine	5,152,756	3,276,062	63.6%
232J	Loblolly-shortleaf pine	3,074,770	1,829,583	59.5%
232J	Longleaf-slash pine	2,685,180	1,447,152	53.9%
Total		32,069,879	17,193,160	53.6%

Source: FIA

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

The simulations projected individual FIA clusters under a variety of silviculture. Even-aged management was simulated in all but the upland hardwood stands where selection management was simulated (Appendix B). An example showing the initial harvest, regeneration, pre-commercial thin, mortality over time, and clearcut cycle is shown in Figure 13 below.

Figures 14 and 15 on the next page show examples of the averaged yields of stored CO_2e for two specific eco-section and forest type combinations. In general, the biomass prescriptions had lower stored carbon than the no-biomass harvest prescriptions. The no-harvest prescriptions generally stored substantially more carbon than the two-harvest scenarios. These results provided inputs to the landscape analysis. There could be significant atmospheric benefits if the landscape were converted to a no-harvest scenario where leakage was limited and alternative energy had a small carbon footprint. This is a scenario that we are currently not experiencing, but there are major initiatives underway to explore the possibilities. The landscape-level no-harvest scenario was not included in our modeling or results.

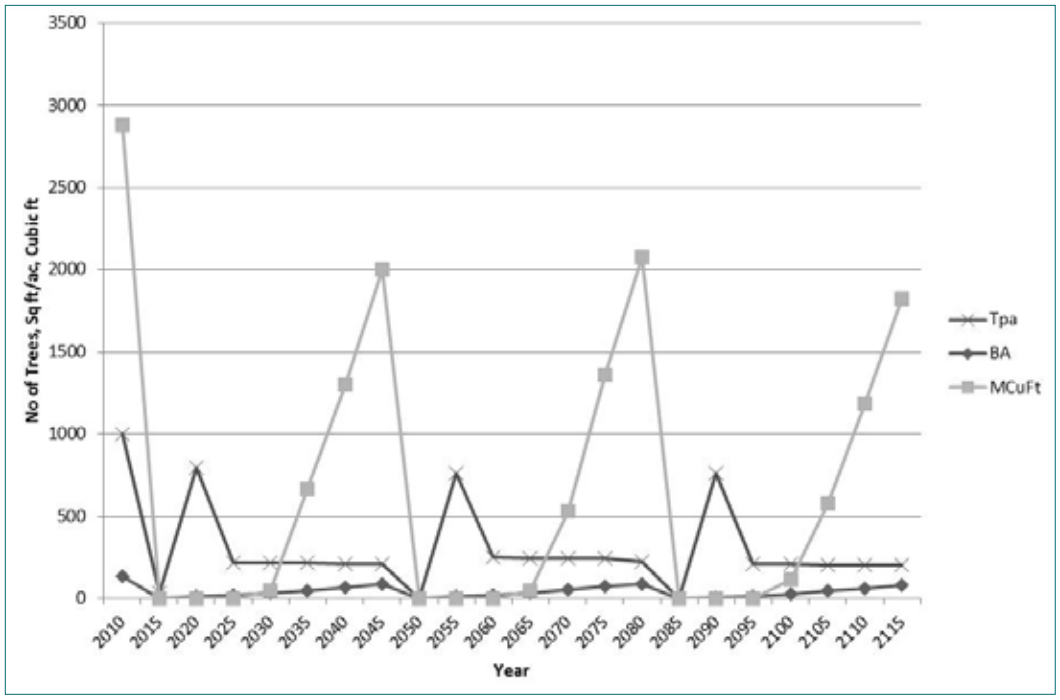


Figure 13.

An example of a plot cluster projection.

This is for a 47-yr old loblolly pine plantation in eco-section 231I, low site, with biomass harvest. A pre-commercial thin occurs early in the rotation, which is seen in the drop in trees per acre (TPA). The basal area (BA) and merchantable cubic foot volume (MCuFt) increase over each 35-year rotation. Slight variations are seen in each rotation due to FVS stochasticity and changes in sprouting species.

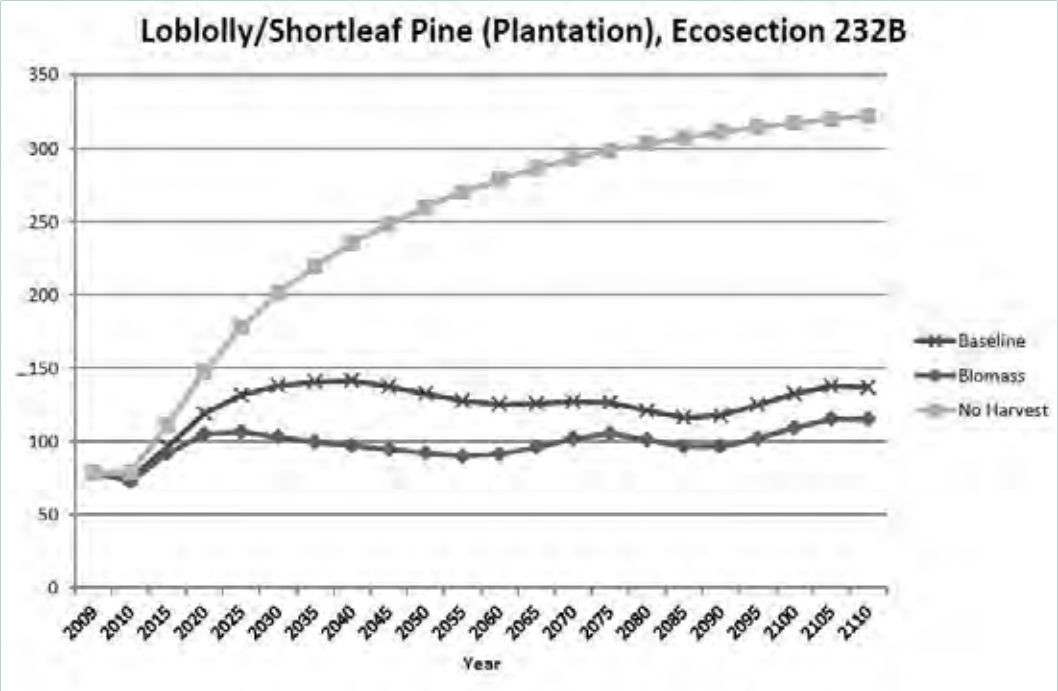


Figure 14.

Averaged projections of carbon storage in the forest and wood products (in-use and landfills) for naturally regenerated loblolly-slash pine in eco-section 231B (Gulf Coastal Plains and Flatwoods) using three silvicultural prescriptions.

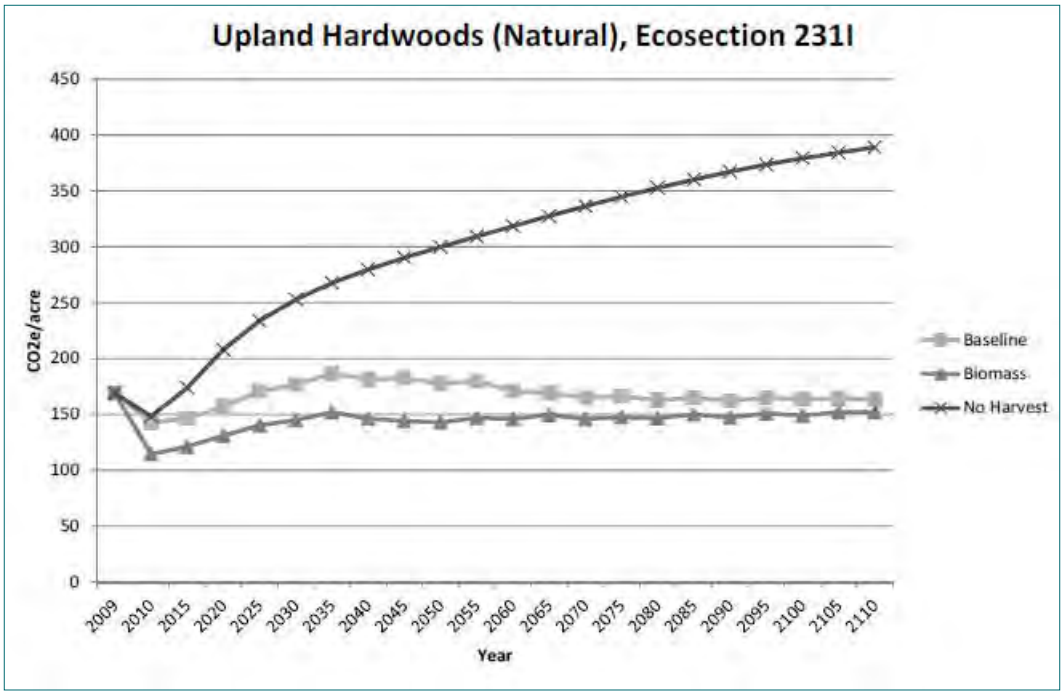


Figure 15.

Averaged projections of carbon storage in the forest and wood products (in-use and landfills) for naturally regenerated upland hardwoods in eco-section 231I (Central Appalachian Piedmont) using three silvicultural prescriptions.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

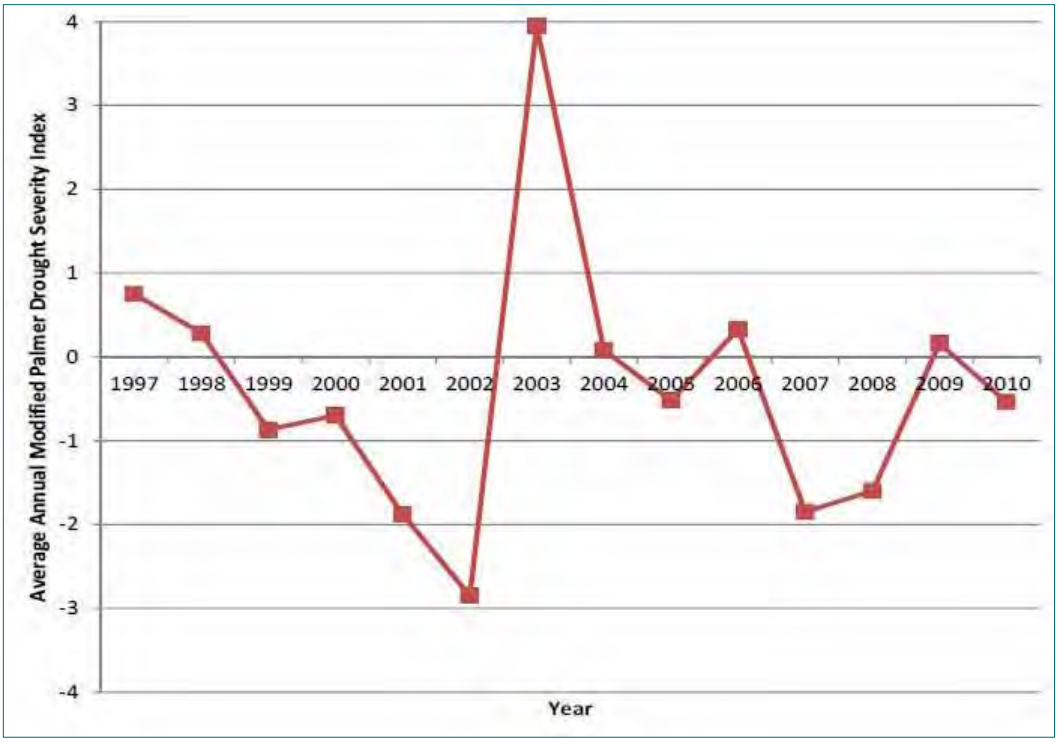
Growth Evaluations

The Southern variant of FVS covers a large geographic region, which may contain deviations from projected average growth locally or regionally. To account for possible bias, the model was evaluated for one of the eco-sections for 5-year bias in above-ground live tree carbon. FIA plots that had been re-measured using the annual inventory method were projected using the FVS carbon model (Rebain, 2010; Jenkins et al., 2003 biomass equations). Plots that had treatments were excluded. The annualized changes in carbon were compared and the model was found to overestimate by almost 60 percent. The period of growth was marked by generally dry-to-drought conditions (see Figure 16 below) however, which makes generalizing conclusions difficult without a longer-time series of data. The FVS functions were fit to data from previous time periods, which were likely nearer normal. The other eco-sections were not examined as the entire Southeast experienced similar climate during this period.

Figure 16.

Average annual modified Palmer Drought Severity Index for the North Carolina Piedmont region.

Palmer classifications are: -4 to -3 severe drought, -3 to -2 moderate, -2 to -1 mild, -1 to 1 dry to normal to wet, >1 wet.



Source: State Climate Office of North Carolina website (www.nc-climate.ncsu.edu)

An additional evaluation was conducted by comparing Loblolly plantation projections of FVS-SN with the projections from the Loblolly plantation model PTAEDA version 4 (Burkhart et al., 2008). Table 32 below shows the results of this comparison. While there were larger deviations for the harvested volumes, total yields were 10-12 percent for the entire rotation. This was felt to be an adequate level of accuracy for a regional analysis.

Finally, overall projections of per-acre yields were subjectively compared to regional averages (McClure and Knight, 1984) and found to be reasonable. This was done for each of the major forest types.

Table 32. Comparison of Simulations Using Non-Biomass Prescriptions for FVS-SN and PTAEDA Version 4

		Ending		Harvest	Total Yield	
Simulator	**Site**	**BA**	**Volume (ft^3/ac)**	**Volume (ft^3/ac)**	**Volume (ft^3/ac)**	**Difference (%)**
FVS-SN	Low	108	2,829	4,113	6,942	10%
PTAEDA		90	3,525	2,740	6,264	
FVS-SN	High	112	3,389	4,616	8,005	12%
PTAEDA		93	3,729	3,345	7,074	

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

3.3.5 Carbon Accounting

The focus of this sub-task was to quantify the GHG implications of different technology types and fuels sources for producing energy in the Southeast. This information will be used to gain a better understanding of the implications for potential energy policy and markets on climate change. This sub-task specifically tracks the fuel production and transportation emissions, facility emissions, and forest carbon dynamics for the region. We analyzed stand-alone electric power and electric-led CHP technology pathways; thermal-led energy pathways were not examined. Carbon yields over time from the forest, harvesting, transportation, and facilities emissions were combined in an Access database where queries were used to produce analysis datasets. These datasets were then read into an Excel spreadsheet for final analysis. Below is a detailed description of the major elements associated with this sub-task.

Major Assumptions

The biomass carbon accounting included the onsite forest pools of above- and below-ground live trees, standing dead wood, and down dead wood. Storage of wood products in in-use and landfill pools was also included. Harvest emissions were estimated using a factor of 0.015 tonnes of CO_2 per bone dry ton (BDT) of material produced. This assumed 16.65 lbs. CO_2 per green ton (Manomet, 2010). Truck transportation emissions were estimated using a factor of 0.000134 tonnes of CO_2 per BDT-mile, which assumed 12.5 tons per truck, 6 miles per gallon and 22.2 lbs. CO_2 per gallon of diesel fuel (EPA, 2005). The miles transported were estimated using the center radius of the transportation rings. Pellet mills were assumed to export 90 percent of their material to northern Europe; an emissions factor of .262 tonnes CO_2 per BDT was assumed for shipping (Henningsen et al., 2000). This was varied for the sensitivity analysis.

Biomass Facilities

Existing and proposed facilities data were assembled by the Southern Environmental Law Center (SELC, 2011). It should be noted that the number of proposed facilities is growing and has grown after the initial data were used as input, including a 75 MW co-gen plant consuming 870,000 tons per year in Covington, Virginia and a new 400,000 ton per year pellet plant in Northampton County, North Carolina.

Each of these facilities had information regarding type of power/fuel, location, status, anticipated supply sources, and capacity. Note that proposed facilities included existing facilities that are closed but may re-open. This analysis assumed that it takes a supply of 6,868 BDT per year per MW for older biomass facilities and 6,244 BDT per year per MW for new biomass facilities (see Appendix A). Biofuel facilities were not considered in this analysis due to their current relatively small impact and uncertain near-term growth.

Biomass Supply and Transportation Emissions

In order to quantify the biomass supply and transportation emissions to facilities, five concentric transportation rings of 10 miles radius from each facility were constructed. This was done for existing and for existing plus proposed facilities (See Figures 10 and

11 on pages 71 and 72). Wood supply for facilities was modeled using distance to the facilities with equal weight given to each; in other words, the distance was equally split between them. Therefore, up to a 50-mile radius was allowed for the wood supply area for a facility unless restricted by neighboring facilities. In practice, there is a lot of overlap in the woodsheds of the proposed facilities. The methodology used in this study was designed to give a conservative estimate of regional transportation emissions by pushing the biomass to the nearest facility.

Source of Supply

Pellet mills were assumed to use only clean chips from merchantable logs that would otherwise be categorized as pulpwood, although not necessarily sold as such as this is determined by local markets. Otherwise, for power plants and CHP, supply was assumed to first be filled by non-merchantable material (residuals) including tops of boles, small trees, and crown branches. If supply was not met by residual material, then wood that met pulpwood merchantable standards was used. Sawtimber was assumed to not be available as biomass feedstock.

Technology Pathways and Facility Emissions

An analysis of the GHG accounting related to biomass energy production may be considered as a function of both the fuel and technology used. We examined 11 technology pathways that varied based on fuel and the kind of energy that was produced. These pathways were selected to represent a likely suite of possible scenarios to be found in the Southeast either currently or in the future and consequently included stand-alone electric power generation and electric-led CHP technologies. Appendix A lists the 11 technology pathways examined along with the attributes of each.

Facility emissions were based on their associated technology pathways. Pellets were assumed to be used in facilities having new energy production from wood pathways (Pathway #2A). Almost all pellets were consumed in European facilities. Emissions were estimated by multiplying the amount of fuel used by a ratio of CO_2 produced per unit of fuel burned. The ratio of CO_2 produced per unit of biomass fuel burned was estimated to be 1:87.

Common Geographic Boundaries

The forested area was defined to be the area of the four eco-sections that included the existing and proposed facility woodsheds, which were defined by a 50-mile radius. By having a common geographic area, the two scenarios of existing facilities and full build out of proposed and existing facilities could be compared. The acreage of proposed facility woodsheds was assigned the baseline no-biomass harvest silviculture when analyzed using existing facilities only. The new facilities would then increase biomass use within the defined landscape.

Pro-Rating Facilities Boundaries

Facilities outside the four eco-sections in the study were included when their 50-mile wood supply radius overlapped with the study area. The wood fiber demand was pro-rated based on the amount of supply area in the study area relative to the entire terrestrial supply area for a facility. Demand for each facility was also adjusted by the amount of supply estimated to be taken from the forest as opposed to wood waste from mills and other sources.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Common Non-Harvested Lands

The sequestration of carbon by non-harvested lands (20.9 percent) did not contribute to the facility-based analysis since it was the same in both the current and full build-out scenarios. The woodsheds of facilities that were partially in the study area were pro-rated based on their acres in the study area relative to their total acreage.

Temporal Period

Annual GHG emissions and forest carbon dynamics were tracked over 100 years on an annual and cumulative basis. In addition to the technology pathways defined by the list of facilities we used, we also considered the GHG implications of producing equivalent electricity or thermal energy using all the non-wood biomass technology pathways.

Forest Carbon Pools

Forest carbon pools that were tracked under the baseline and treatment scenarios included live tree above and below ground, standing dead above and below ground, lying dead wood, and wood products storage in in-use and landfill pools. The carbon submodel of the FVS-FFE extension (Rebain, 2010) was used for carbon estimates in live trees and dead wood. The set of allometric equations from Jenkins et al. (2003) were used for live tree biomass estimates, above and below ground. FVS-FFE can use the Jenkins equations, which rely on species and dbh, down to a 1-inch dbh tree. Below 1-inch is interpolated. Wood density, which varies by species, is multiplied by the volume to get biomass estimates. Below-ground dead biomass occurs when trees die or are harvested. FVS-FFE uses a default root decay of 0.0425, which is what we used. Aboveground dead biomass used the FVS-FFE functions.

Wood Products Storage Pools

Wood products storage pools were estimated from the DOE 1605(b) guidelines (DOE, 2007). This was implemented in FVS-FFE based on the 2002 regional estimates (Adams et al., 2006) from Smith et al. (2006). Harvested trees less than 9 inches dbh for softwood and 11 inches dbh for hardwood were assumed to be in the pulpwood merchandising category; larger trees were assumed to be used as sawlogs. The age classes of the wood products pools for in-use and landfill were tracked by FVS-FFE with age 0 at the beginning of the 5-year period where harvest was simulated. Two other wood product pools were available—the emitted with energy capture and emitted without energy capture—but these were ignored for this analysis since this data feeds into an energy-use analysis.

Carbon Pools NOT Tracked

The soil, forest floor, and understory vegetation were not tracked due to the expectation that there would not be significant changes in these pools between the scenarios (Gershenson et al., 2011) and because of the lack of accurate prediction models.

Estimating Carbon Stock Changes

Changes in carbon stocks over time were used to estimate GHG flux between the biosphere and atmosphere. Biomass was converted to carbon by multiplying by 0.5 (Penman et al., 2003; Rebain, 2010). Carbon was converted to CO_2 equivalence (CO_2e) by multiplying carbon estimates by 3.67, which is the ratio of the atomic weights. CO_2e was reported in metric tons (tonnes) per acre or in total tonnes. All results were reported in CO_2e.

Estimating Methane Production

Methane production from slash burning was estimated using the CO_2 emitted from the biomass burned multiplied by a factor of 0.07 (CDM 2011; IPCC 2006) increasing the emissions by 7 percent. Methane production from decomposition of dead wood in the forest was assumed to be negligible (e.g., IPCC, 2006).

3.3.6 Sensitivity Analysis

A model, including the parameters indicated above, was constructed to analyze the GHG consequences of two different levels of biomass utilization and power production in the Southeast. To help examine the effects of varying different potential market and policy actions, the model was designed to manipulate four different parameters. These parameters were set to default settings for the basic analysis of the two scenarios. Then the parameters were altered to see if they resulted in significant changes to the atmospheric carbon profiles of the two scenarios and to answer the specific questions asked of the study. The following four factors were used for the basic sensitivity analysis:

- ***Wood Supply Directly from the Forest (Forest Supply).*** Some existing and proposed facilities receive 100 percent of their biomass supply either from the forest or from non-forest sources such as mill residues or urban tree trimmings. Some facilities, however, claim a variable amount of their supply directly from the forest; for those facilities we varied the forest supply by setting it at 20 percent, 50 percent, and 80 percent.
- ***Wood Supply from Pulpwood (Pulp Supply).*** Where appropriate (non-pellet mills), residuals were used to fulfill biomass demand first and pulpwood was used when needed. Given that competition may exist for pulpwood for use as pulp and paper, we set limits on the availability of pulp at 0 percent, 50 percent, and 100 percent. For example, a 0 percent from pulpwood would mean that there is no pulpwood allowed in the system for biomass utilization and more residuals would have to be produced.
- ***Wood Supply from Residuals (Non-Merchantable Supply).*** There are physical, economic, and Best Management Practices (BMP) limits to how much of the residuals (non-merchantable wood, bark, foliage) can be removed from the forest. We examine the implications of this by setting the amount of residual removal at 30 percent and 60 percent.
- ***Export of Wood Pellets (Pellet Exports).*** to northern Europe was set at 90 percent and 40 percent.
- ***Efficiency of Biomass Utilization.*** Examined a higher biomass requirement per MW-year of power produced, which was 8,234 BDTs per year per MW for older less-efficient biomass facilities and 6,868 BDTs per year per MW for newer, more-efficient biomass facilities. This specific parameter was examined in its own separate analysis and was not included in all combinations of the general set of 4 parameters described above.

The sensitivity analysis was run using multiple scenarios that allowed the research team to test individual parameters. The scenarios, parameters, and their values were developed using a collaborative process that took into consideration local knowledge, field data, and existing literature. All results are reported for existing facilities and proposed facilities across the entire study area. A list of the simulations used can be found in Table 33 on the following page.

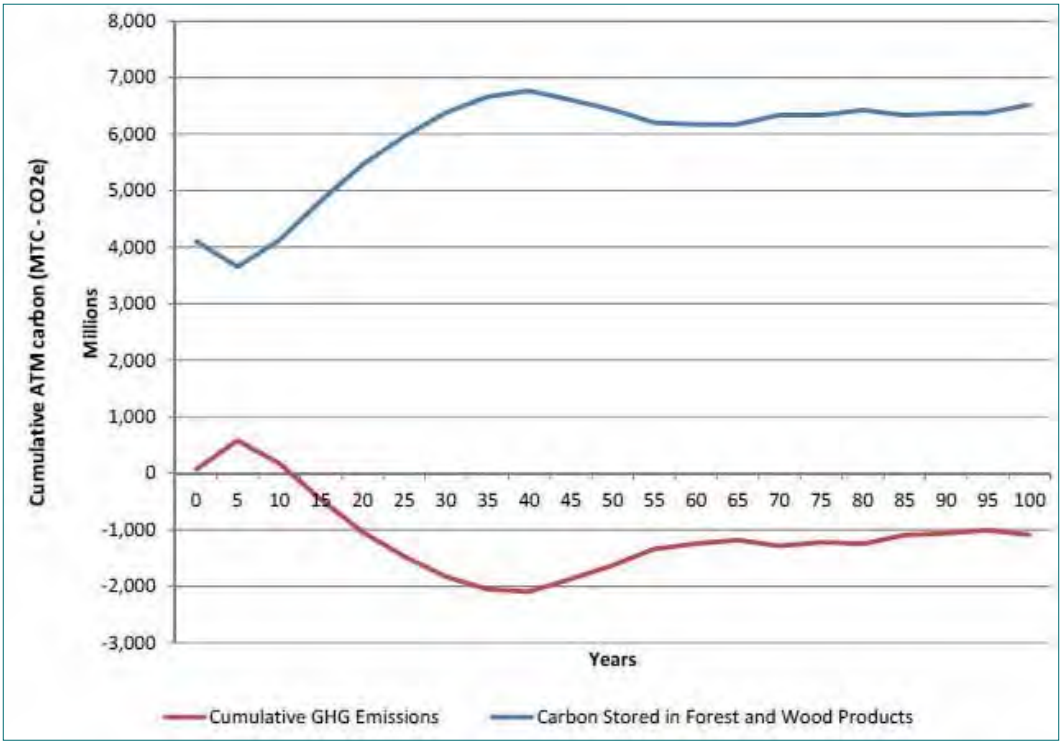
3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Table 33. Summary of Sensitivity Analysis Scenario Development (percent)

Scenario	Efficiency (BDTs/MW-yr)	FA: Forest Supply	PS: Pulp Supply	NM: Non-Merchantable Supply	EP: Pellet Exports
Default	**6868 old/6,244 new**	**50**	**50**	**60**	**90**
Forest Supply Min.	6868 old/6,244 new	**20**	50	60	90
Forest Supply Max.	6868 old/6,244 new	**80**	50	60	90
Pulp Min.	6868 old/6,244 new	50	**0**	60	90
Pulp Max.	6868 old/6,244 new	50	**100**	60	90
NonMerch Min.	6868 old/6,244 new	50	50	**30**	90
Pellet Export Min.	6868 old/6,244 new	50	50	60	**40**
Facility Efficiency	**6868 high/8000 Low**	50	50	60	90

Figure 17.

Cumulative atmospheric carbon balance of existing facilities over time (lower line) and carbon stored in the forest, in-use wood products, and landfills (upper line).



3.4.0 FINDINGS

In order to understand the implications of market and policy drivers in the development and expansion of a biomass electric power market in the Southeast, we analyzed the current condition and a scenario adding 22 additional biomass power plants to represent the proposed expansion of the biomass power sector in the Southeast over the next few years. A study of actual (and proposed) facilities in the context of the forested landscape and fiber supply area provided a more realistic analysis than a hypothetical comparative analysis. This analysis produced several key findings based on the questions defined above.

The 22 facilities selected for this simulation are all proposed for the next few years and there is the likely possibility that there will be more facilities planned, in addition to the 22, over a longer time period. Findings are presented in this report using the following format:

- **Question.** Define key policy question
- **Result.** Describe the key result from the analysis
- **Explanation.** Describe how the model and sensitivity tools were used to answer the question and discuss key findings

1. What are the atmospheric carbon implications of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?

Result. Our findings indicate that the existing biomass facilities examined were generally producing improved atmospheric carbon balance relative to fossil fuels and technologies to provide equivalent power at the regional scale. The macro-patterns remained the same for all the sensitivity-level combinations, including Wood Supply Directly from the Forest (Forest Supply), Wood Supply from Pulpwood (Pulp Supply), Wood Supply from Residuals (Non-Merchantable Supply), and Export of Wood Pellets (Pellet Exports). This would suggest that continuing to run these existing biomass power plants as they are currently sized and scaled today would result in lower atmospheric carbon in the short and long term than shutting them down and shifting to fossil fuels.

Explanation. There were 17 existing biomass electric power facilities (producing 159 MW and 1,775,000 tons of pellets) identified in the study area. The GHG profile produced was a function of the modeling of forest growth, harvest, and mortality; facility emissions based on identified technology pathways; and transportation and extraction emissions. We first present the atmospheric carbon balance for the existing facility landbase, without consideration of proposed facilities. The difference between the carbon storage using biomass harvests and baseline harvests without biomass is incorporated into the profile.

The cumulative atmospheric carbon balance is shown in the lower line in Figure 17 on the previous page. The shape of the cumulative emissions incorporates and is driven by the carbon storage factor, which is illustrated in the top line of Figure 17. The specific nuances of the curves are a function of modeling assumptions and harvest scheduling; the trend of the lines over time is primarily of interest.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 18 on the following page shows the cumulative carbon balance comparison of the existing biomass energy facilities (red line in Figure 17) compared to other possible means to meet the same energy demand. Emissions are occurring as harvests are initiated, which is the positive "bump" in the beginning of the line. After the initial emissions, the biomass scenario generally emits less carbon to the atmosphere than the other fuels and pathways. The specific shape of the curve is largely driven by modeling parameters; we are interested in the general trends.

In order to compare the effects of building the proposed biomass facilities, we need to consider the effects on the forested acres impacted by those new facilities. When only existing facilities are in place, those acres outside existing facility woodsheds, but destined to be included in the acreage of the proposed facility woodsheds, were modeled using a business-as-usual (BAU) harvesting scenario that did not include biomass harvesting.

The difference in the carbon balance between the two land bases is illustrated in Figure 19 on page 92. The larger land base sequesters more carbon because the additional acres are sequestering more carbon and are not being biomass harvested. This full land-base analysis will be needed when calculating the effects of the full build-out. This allows us to factor in those acres that are not currently being harvested for biomass utilization in the BAU.

Sensitivity Analysis of Running Existing Facilities

We tested whether the atmospheric carbon balance of the existing biomass facilities relative to the other pathways can be changed by altering the assumptions. When the parameters for the four other assumptions are varied, no significant change in carbon balance was identified (Figure 20). The macro pattern, however, compared to fossil fuel type remains the same for all scenarios modeled (they were all beneficial).

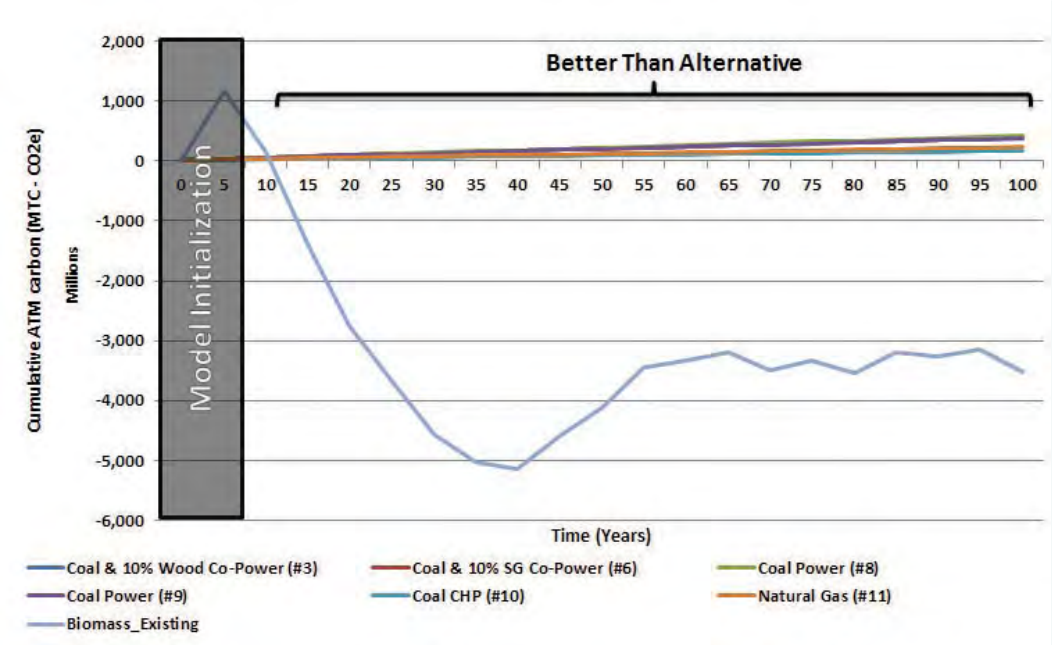


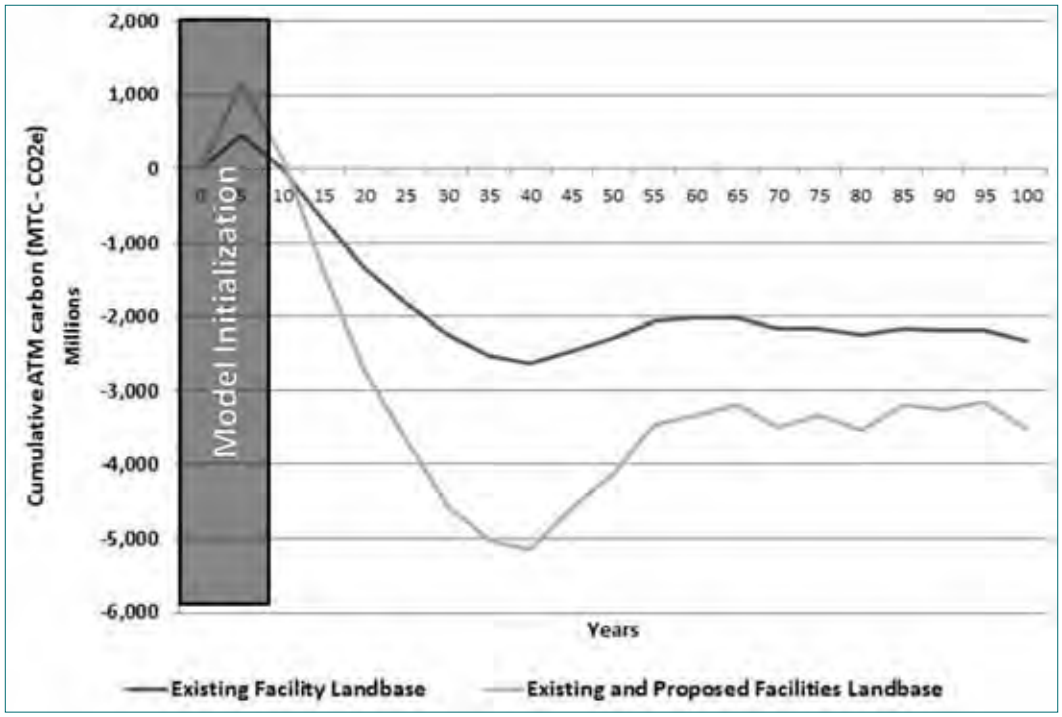
Figure 18.

Cumulative carbon balance of existing biomass facilities with other pathways for comparison.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 19.

Comparison of the carbon balance for the existing biomass facilities considering different forested land bases: the woodsheds of the existing biomass facilities versus the full build-out acres.



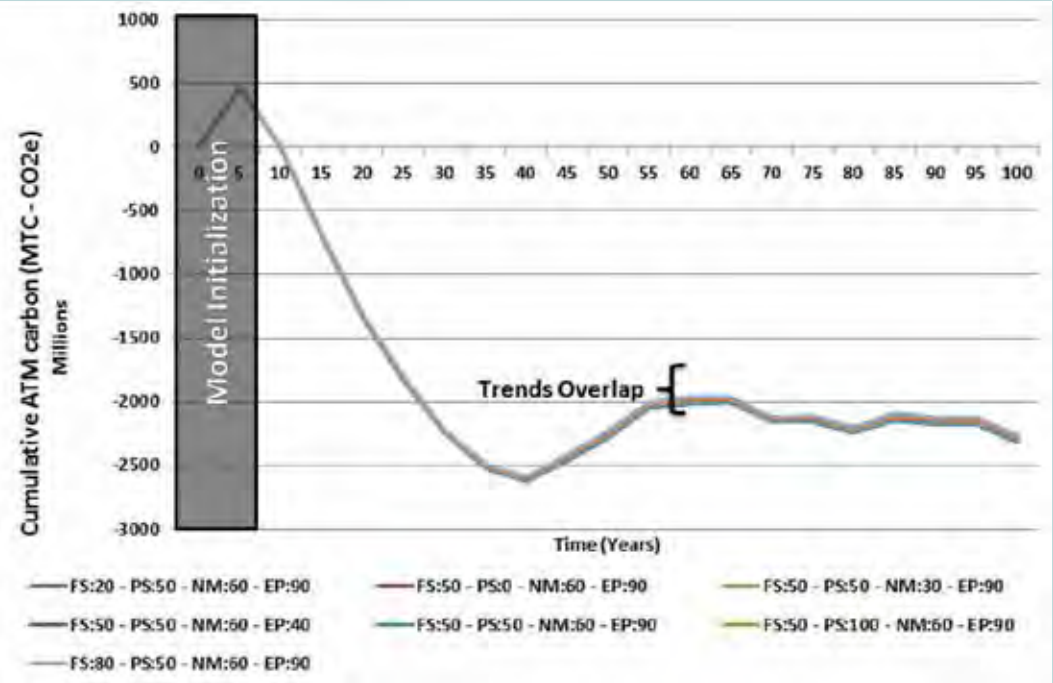


Figure 20.

Sensitivity Analysis Conducted for Existing Biomass Facilities.

Results are presented in the following order: Wood Supply Directly from the Forest (FS: Forest Supply) at 20, 50, and 80 percent, Wood Supply from Pulpwood (PS: Pulp Supply) at 0, 50, and 100 percent, Wood Supply from Residuals (NM: Non-Merchantable Supply) at 30 and 60 percent, and Export of Wood Pellets (EP:Pellet Exports) at 40 and 90 percent. The table is keyed in the following format: Forest-Pulp-NonMerch-Pellet. The lines overlap showing that there is no difference between them from a cumulative atmospheric carbon point of view.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

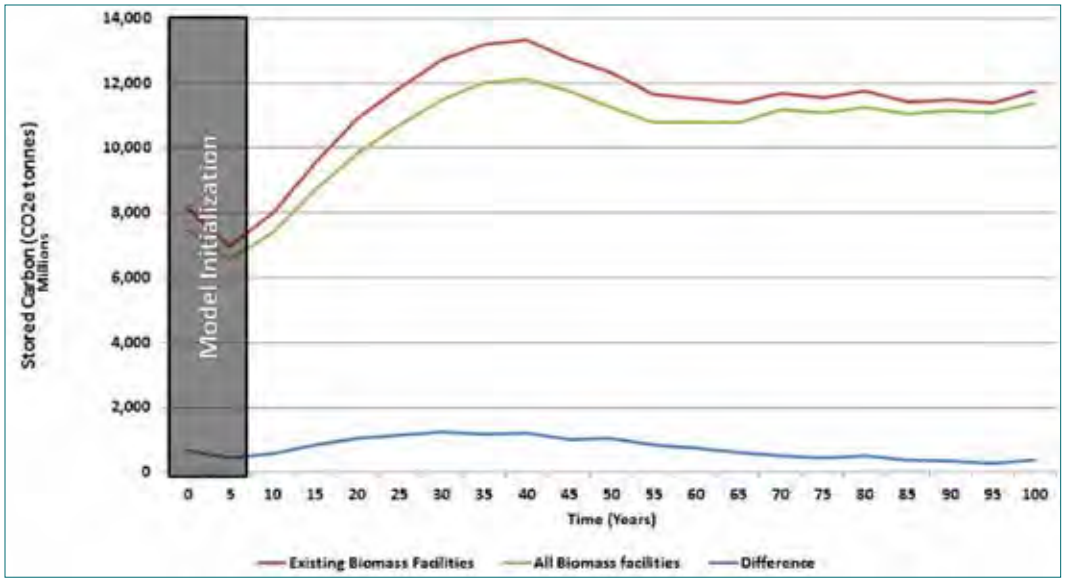


Figure 21.

Forest and long-term carbon storage (wood products and landfill) for the existing biomass facilities, full build-out of proposed biomass facilities and existing facilities, and the difference between the two (proposed facilities).

2. What are the atmospheric carbon implications of operating the existing biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants?

Result. Additional biomass facilities had reduced long-term atmospheric carbon relative to other fuels and technology pathways at a short-term atmospheric carbon cost. The biomass option recovered the carbon debt in 35-50 years depending on the fossil fuel scenarios being compared. The macro-patterns remained almost the same for all the sensitivity-level combinations, including Wood Supply Directly from the Forest (Forest Supply), Wood Supply from Pulpwood (Pulp Supply), Wood Supply from Residuals (Non-Merchantable Supply), and Export of Wood Pellets (Pellet Exports). The results were sensitive to biomass efficiency.

Explanation. We identified a total of 39 facilities, 17 existing, and 22 proposed facilities. The additional 22 biomass power facilities represented 1,014 megawatts of electricity and 3,050,000 tons of pellets. Actual information from facility applications and other public sources, as compiled by SELC (2011), was used to represent the proposed expansion of the biomass electric generating sector in the Southeast over the next several years. The proposed facilities increased demand for wood fiber by 5.2-6.3 million tons a year depending on assumed biomass operational efficiencies (see next section).

We examined the GHG implications of meeting the increased demand using the proposed biomass facilities and compared that to coal and natural gas technology pathways.

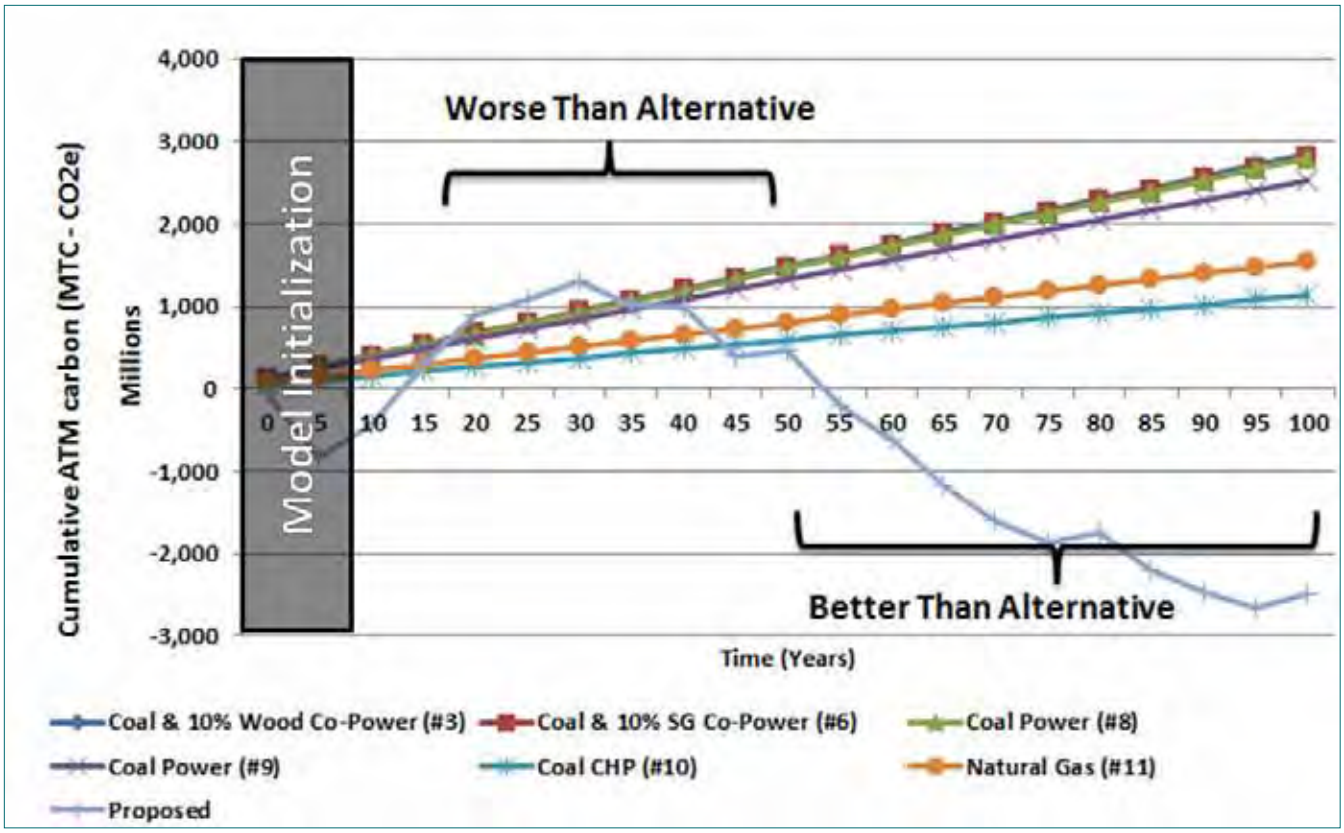


Figure 22.

Cumulative atmospheric carbon balance over 100 years using coal, and natural gas technologies to meet energy demand of proposed biomass facilities.

Biomass baseline for proposed facilities is shown for comparison. Coal #3 and #6 are hidden under coal #8. These results were based on the following assumptions: Forest Supply 50%, Pulp Supply 50%, Non-Merchantable Supply 60%, and Pellet Export 90%.

Assuming full build-out of the currently proposed facilities using biomass energy, we examined the atmospheric carbon balance effects of varying assumptions regarding pulpwood utilization, residual extraction from the forest, amount of woods-supplied versus residue-supplied raw material, pellet mill exports, and biomass efficiency.

Biomass Facility Build-out

A full build-out of the currently proposed biomass facilities requires biomass harvesting to occur in the woodsheds of those facilities. Relative to the existing facility situation this causes a reduction in stored carbon, which varies over time. Figure 21 shows the stored carbon for the existing biomass facility and full build-out facility scenarios, along with the difference between the two scenarios. The difference characterizes the stored carbon impacts of the 22 proposed facilities. The curve generally shows an increase in atmospheric carbon between the two scenarios for about 40 years before leveling off.

The actual shapes of the cumulative carbon balance lines (red and green lines) in Figure 21 will vary depending on many policy and market factors. We are not attempting to make a prediction of the actual future condition, but are interested in a realistic depiction of the difference between the two scenarios. The initial apparent sequestration in the graph is a modeling artifact. It is a function of the simulation resolution and is due to the 5-year simulation cycle with harvests simulated mid-decade. This creates a 5-year growth period before harvest simulation.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Comparison of Biomass to Other Technologies for Build-out

The use of the proposed biomass facilities for full build-out was used as a reference to compare against other technology options for meeting the same energy demand. Figure 22 on the previous page shows the cumulative atmospheric carbon balance for various fuels and technologies relative to producing the same amount of energy using biomass for the proposed facilities. These scenarios include the carbon storage that would have occurred without the proposed biomass facilities being utilized.

In all cases the alternatives appear to have fewer net atmospheric carbon emissions than biomass for 35-50 years with biomass having fewer emissions after that time.

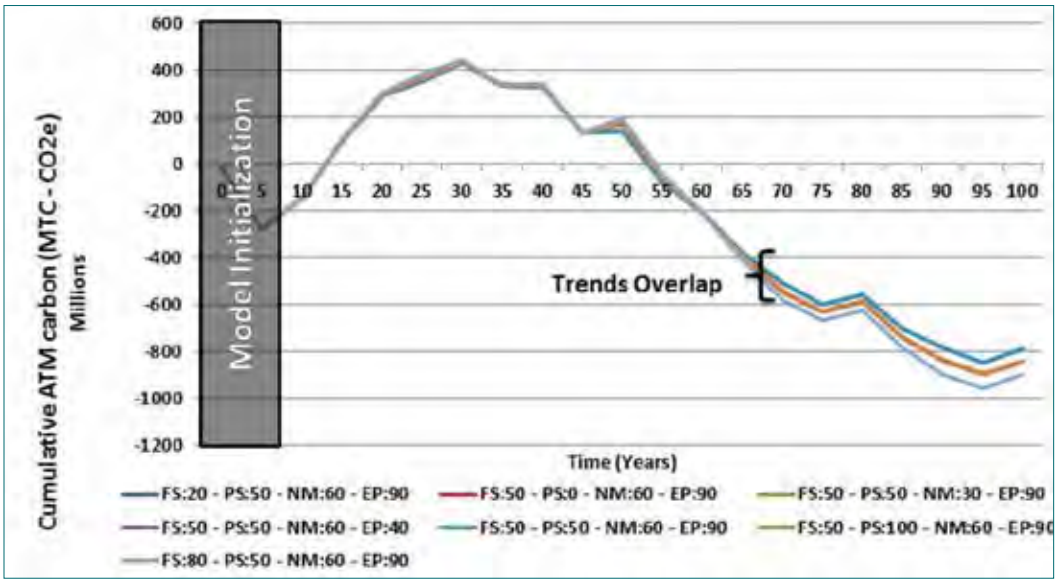


Figure 23. Sensitivity Analyses Conducted for New Biomass Facilities.

Results are presented in the following order: Wood Supply Directly from the Forest (FS: Forest Supply) at 20, 50 and 80 percent, Wood Supply from Pulpwood (PS: Pulp Supply) at 0, 50, and 100 percent, Wood Supply from Residuals (NM: Non-Merchantable Supply) at 30 and 60 percent, and Export of Wood Pellets (EP:Pellet Exports) at 40 and 90 percent. The table is keyed in the following format: Forest-Pulp-NonMerch-Pellet. None of these changes caused a substantial shift in atmospheric carbon.

The CHP scenarios for coal was the best due to the efficiency improvements with CHP. In general, natural gas performed the best of the nonrenewable fuel/technology scenarios without CHP technology (Figure 22, #11 line). Coal power showed a range of responses that depended on the technology pathway. Soil sequestration and land-use change were not considered with any scenarios.

The performance of the proposed biomass facilities relative to the other fuels/pathways was primarily due to the change in forest and long-term carbon storage that was modeled to occur with the increased biomass demand. These results were examined when the input parameters were varied.

Sensitivity Analysis of Full Build-out Using Biomass

A number of input assumptions were varied to observe the response in atmospheric carbon for the 22 proposed biomass facilities. Four primary sensitivity parameters were analyzed: wood supply directly from the forest, wood supply from pulpwood, wood supply from residuals and the amount of export of wood pellets to Northern Europe. In addition, the assumptions regarding the efficiency of the biomass facilities were varied for an additional analysis. None of the four primary input assumptions showed a substantial shift in atmospheric carbon (see Figure 23 on the previous page). The biomass efficiency assumption was analyzed separately for the full build-out scenario and is illustrated in Figure 24 on page 98.

IMAGE COURTESY ZANDER EVANS

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

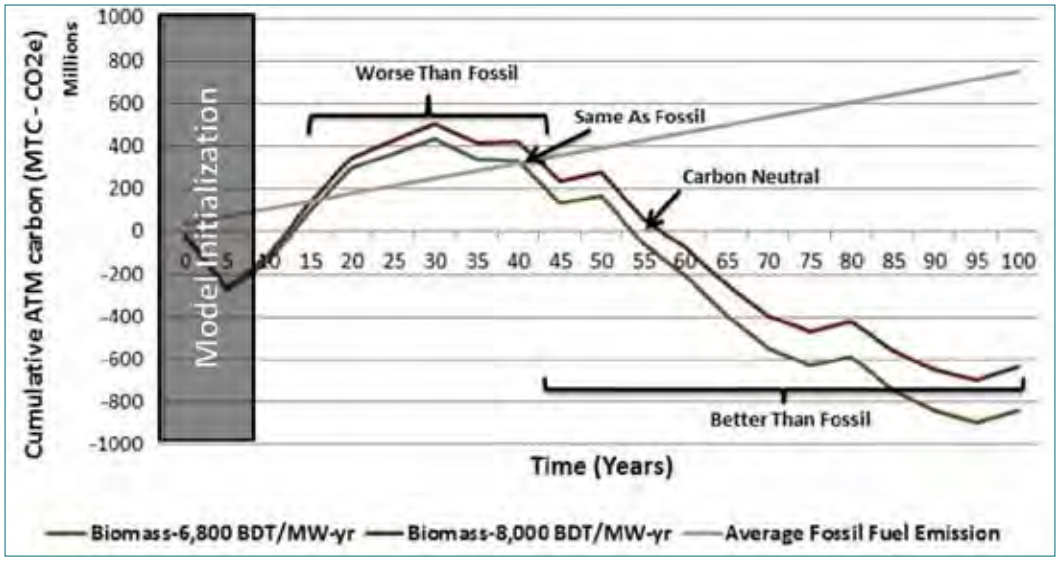


Figure 24.

Facility Efficiency.

Both systems have short- term cost and a long-term benefit. When the biomass line is above the fossil fuel line, then it is emitting more carbon into the atmosphere compared to the fossil fuels. The atmospheric carbon impact is the same where the lines intersect. Carbon neutrality is achieved when the biomass line intersects the origin. This simulation was run using the following assumptions: (Forest Supply) 50%, (Pulp Supply) 50%, (Non-Merchantable Supply) 60 %, and (Pellet Exports) 90%.

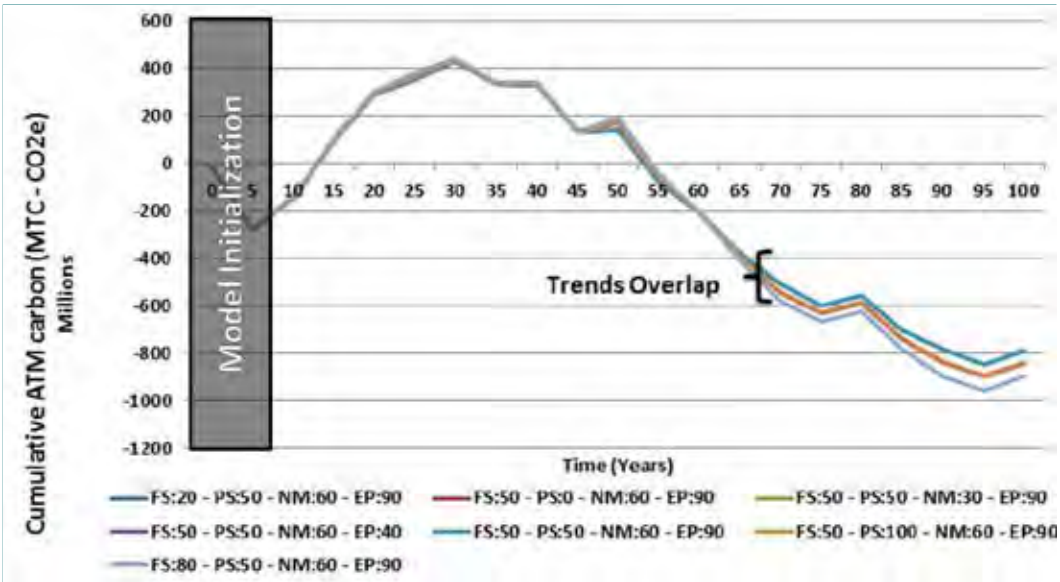


Figure 25.

Sensitivity Analyses Conducted for Wood Supply Directly from the Forest (Forest Supply) at 20, 50, and 80%, Wood Supply from Pulpwood (Pulp Supply) at 50%, Wood Supply from Residuals (Non-Merchantable Supply) at 60%, and Export of Wood Pellets (Pellet Exports) at 90%. The table is keyed in the following format: Forest. FS:20 and FS:50 overlap.

3. What are the GHG consequences of varying the amounts of biomass required to make a specific amount of electricity?

Results. Biomass utilization per unit of power produced was a critical factor and can alter the outcome of the atmospheric carbon balance over time. We showed that a more conservative (higher) assumption of biomass demand per unit of power produced altered the eventual outcome and delayed the breakeven point relative to the other fuels and pathways. There are a range of values associated with how much biomass is required to produce a given amount of electricity. Using a mid-range target of 6,868 BDT per MW per hour per year provided the payback period of 35-50 years. The model was sensitive to this parameter and payback periods were extended when the high range of about 8,000 BDT was used.

Explanation. The model was sensitive to the biomass facility efficiency assumptions. The proposed facilities are compared to the other fuel and technology pathways assuming the high end of a range of possible biomass requirements for power production (see Figure 24 on the previous page). In this figure, the other technology pathways were averaged to achieve a single carbon accumulation line. The less-efficient assumption yielded higher cumulative atmospheric carbon due to the fact that the facilities consumed a larger amount of biomass. Specific details behind this value can be found in the technology pathways section of the report.

4. What are the GHG consequences of using forest-derived biomass versus non forest-derived biomass?

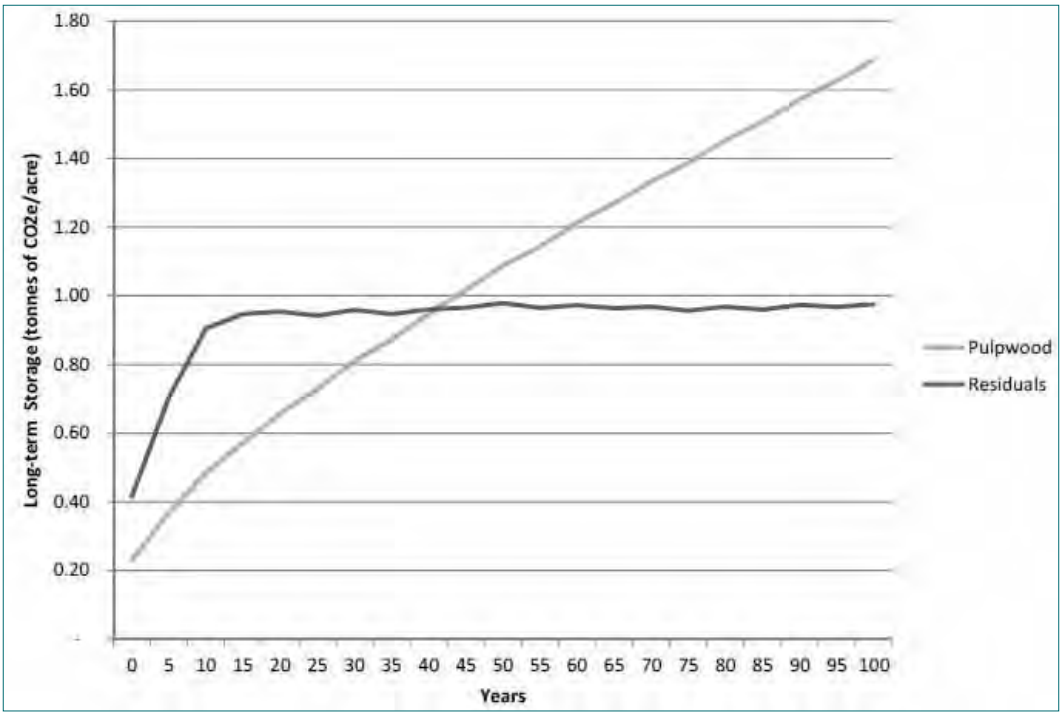
Results. The forest supply sensitivity analysis did not cause a substantial difference for the scenarios modeled at the landscape scale.

Explanation. There was sufficient biomass supply from the forest for the existing and proposed facilities within the landscape of interest using the defined assumptions. The model used the best available information on specific facility use of forest versus non forest-derived biomass. Local supply issues could occur where facility woodsheds overlap, which could have ecological impacts if best management practices for wood retention are not in place. Some biomass facilities receive 100 percent of their biomass supply from the forest or from non-forest sources such as mill residues or urban tree trimmings. Some facilities, however, claim a variable amount of their supply directly from the forest; for those facilities we varied the forest supply by setting it at 20 percent, 50 percent, and 80 percent. The sensitivity analysis does not show a substantial difference between these scenarios over the short term (see Figure 25 on the previous page). Over the long term, the results indicate a slightly lower atmospheric carbon profile for supply coming directly from the forest. Our results were surprising. We expected a benefit from using non-forest biomass feedstocks considering that this biomass has lower processing and transportation emissions as well as avoided decomposition emissions benefits. We found that at the regional scale there were no significant differences in landscape level GHG accumulation because the integrated carbon profiles of the different feedstocks were similar to one another (the net magnitude of emissions between the processing, transportation, and avoided decomposition) and the forest was responding with increased growth and storage of wood products when forest material was harvested for biomass.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 26.

Example of the relative carbon storage over time of pulpwood utilized for pulp and paper products versus residuals retained in the forest.



5. What are the GHG consequences of using tops and limbs (residuals) for biomass supply versus pulpwood (main stems)?

Results. The residual versus pulpwood supply sensitivity analysis did not cause a substantial difference for most of the scenarios modeled at the landscape scale, however, this result needs to be considered in the context of the model. The use of residuals versus main stems would reduce atmospheric carbon accumulation in those situations where there are adequate amounts of residuals available from current harvests. This conclusion is based on the higher relative carbon storage of pulpwood versus residuals (see Figure 26 above). This general rule also holds true for situations where no pulp market exists and standing trees might be left to grow and sequester carbon.

Since residuals are not the driver of timber harvests, when a landscape model is asked to service biomass facilities only from residuals and the required amount of residuals is not readily available from timber harvests, it causes more acres to be harvested. Thus, when this model was instructed to supply the 22 new facilities with only residuals, it did not cause a substantial difference in the GHG consequences versus pulpwood.

An accurate depiction of the pulpwood versus residual utilization comparison requires a spatially specific and market dependent analysis beyond the scope of this study. Such a study would incorporate different market scenarios that would influence the carbon emissions such as: active sawtimber market, active sawtimber and pulp market, no markets, and active pulp market.

Explanation. An analysis of pulpwood utilization relative to residuals is complicated by the fact that more acres are generally required using residuals to supply the same quantities of biomass. Since harvests are integrated for sawtimber, pulp, and residuals, the emissions increase to obtain residual biomass supply because more carbon is removed from the forest through more harvesting. These results at the model scale should not lead to erroneous conclusions regarding the GHG differences of standing trees versus residuals because residuals are not drivers of timber harvest, but rather by-products. This comparison does not include leakage effects that might occur if biomass demand were to cause pulpwood supply to shift to other areas.

Pulpwood

The percentage of pulpwood utilized relative to harvest residuals was varied at 0, 50, and 100 percent of pulpwood utilization. In the context of the entire study area, there was not a substantial tradeoff identified between utilizing pulpwood that was destined to be made into pulp and paper products and using the same material for biomass energy (see Figure 27 below). This was not a complete life-cycle analysis in that the pulp and timber markets were not analyzed, including potential leakage effects of displaced pulp supply.

Designing a More Accurate Model for the Residuals versus Main-Stems Question

A complete depiction of the pulpwood versus residual utilization comparison requires a spatially specific and market-dependent analysis beyond the scope of this study. For simplicity in framing the conceptual model, we are assuming that no competition from other biomass facilities exists, however, the map of existing and proposed facilities (see Figure 11 on page 72) shows that a number of facilities have overlapping sourcing areas. This could cause a situation where biomass is being moved farther distances for use in facilities designed with different efficiencies driven by specific market demands.

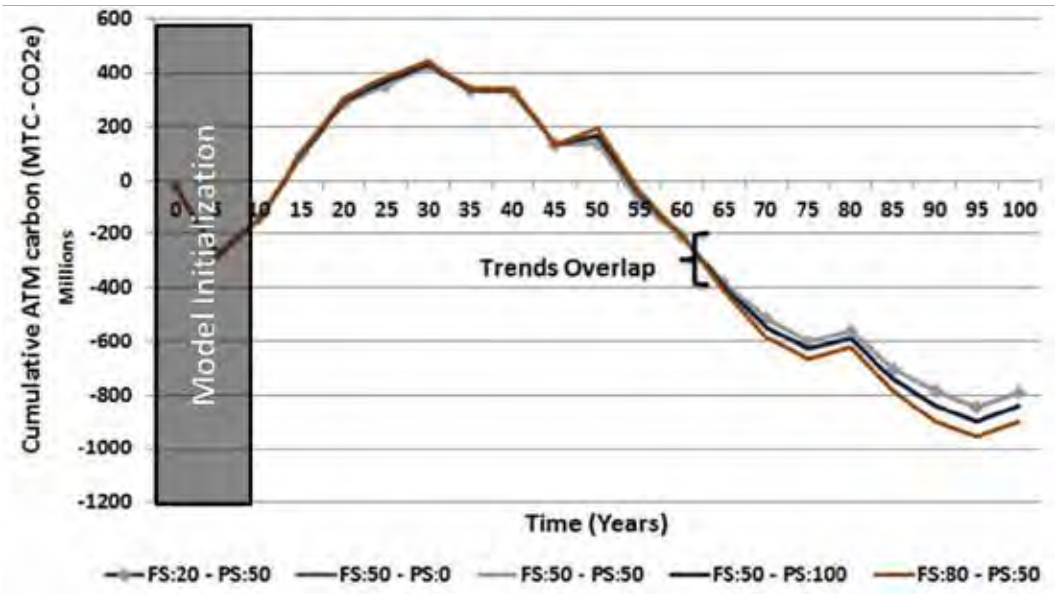


Figure 27.

Sensitivity Analyses Conducted for Wood Supply Directly from the Forest (Forest Supply) at 20, 50, and 80% and Wood Supply from Pulpwood (Pulp Supply) at 0, 50, and 100%, Wood Supply from Residuals (Non-Merchantable Supply) recovered at 60%, and Export of Wood Pellets (Pellet Exports) at 90%. The table is keyed in the following format: Forest-Pulp. FS-PS, 20-50, 50-50, and 50-0 all overlap.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Market demands could be incorporated into a future study by defining different market scenarios that would influence the carbon emissions such as: active sawtimber market, active sawtimber and pulp market, no markets, and active pulp market.

Scenario 1-Active Sawtimber Market. This setting includes intensive sawtimber activity in the proposed facility woodshed and no existing pulp demand. In this case, we assume that an ample supply of both residuals and pulpwood is available. Since there is no existing residual or pulpwood demand, we can assume that when a sawtimber harvest occurs, this wood is either left to become emissions over time from decay if part of a sawtimber tree, or if a partial harvest, left on the stump. The larger harvested pulpwood pieces will take longer to decay so there is a timing element, but in general either of these sources for biomass would have the same atmospheric carbon effects when derived from sawtimber trees. This is because neither source was being utilized a priori. Leaving the pulpwood-size pieces on the stump and utilizing the residuals from the harvested sawtimber, however, will clearly be beneficial from an atmospheric carbon perspective.

Scenario 2-Active Sawtimber and Pulp Market. This setting includes intensive sawtimber activity in the proposed facility woodshed and existing pulp demand. In this case, we assume that an ample supply of residuals exists, but pulpwood is already being utilized for paper products with the associated long-term storage in in-use and landfill pools. Since there is no existing residual demand, we can assume that when an integrated sawtimber and pulpwood harvest occurs that the residual wood is left to become emissions over time from decay. In general, using residuals will have improved atmospheric carbon effects relative to pulpwood. This is because the residuals were not being utilized a priori while a portion of the pulpwood was placed into long-term (100-year) storage. Taking the pulpwood instead of the residuals would cause the long-term storage to be negated; this would be offset in the shorter term by more residuals in the woods but that would reach a steady state. Also, if this meant a displacement of pulp supply, then the carbon analysis would depend on the leakage effects. This scenario fits with much of the "existing" landscape condition in the Southeast; except of course for the recent drop-off in timber production. For example, sawmills in Alabama are currently running at about 50 percent capacity.

Scenario 3-No Markets. This setting includes a low level of sawtimber activity in the proposed facility woodshed and no existing pulp demand. In this case we assume that a low level of supply of both residuals and pulpwood is available. In order to provide biomass supply, harvests would have to be initiated based on biomass demand, not as a side consequence of other harvests. In this case it might seem logical to utilize both pulpwood and residuals from harvests. This might minimize the reduction of stored carbon in the forest, not considering land conversion issues, by minimizing the acres harvested. Relative to a baseline of no harvest, however, this would not be beneficial to the atmospheric carbon balance. There would likely be some acreage in this category where a biomass market may make marginal harvest scenarios profitable. We did not attempt to quantify this effect for the study area.

Scenario 4-Active Pulp Market. This setting includes a low level of sawtimber activity in the proposed facility woodshed and an existing pulp demand. In this case, we assume that a supply of both residuals and pulpwood is available, but pulpwood is already being utilized for paper products with the associated long-term storage in in-use and landfill pools. Utilizing the residuals associated with pulpwood harvests would have the most beneficial carbon effect. This illustrates that a pulpwood- versus residual-utilization question is really a site specific one, which has policy implications regarding GHG accounting for a proposed facility. Our modeling did not account for this level of sophistication, which would require a spatially explicit timber/pulp supply model.

Professional forestry and forest management have long been involved with the sustainable production of wood fiber for use by society. The production of wood fiber for biomass energy affects the amount of carbon exchange between the biosphere and atmosphere through both the production of energy and carbon stored on the landscape and in other pools. By accounting for these flows, we can identify when landscapes may become limiting to sustainable and environmentally favorable outcomes. We have assumed in our modeling here that any harvesting will be followed by replanting or natural regeneration so that all stands are fully restocked in a reasonable and relatively short time frame.

This analysis can inform policy and management decisions. We can also use our existing tools of silviculture and planning to assist with mitigating effects where feasible for the best environmental and economic outcomes. The accounting for the consequences of atmospheric carbon balance relative to a baseline that is geographically constrained to the affected area is consistent with project carbon accounting as found in forest protocols for carbon projects.

6. What are the GHG consequences of using natural stands versus plantations to fuel an expansion of biomass electric power in the Southeast?

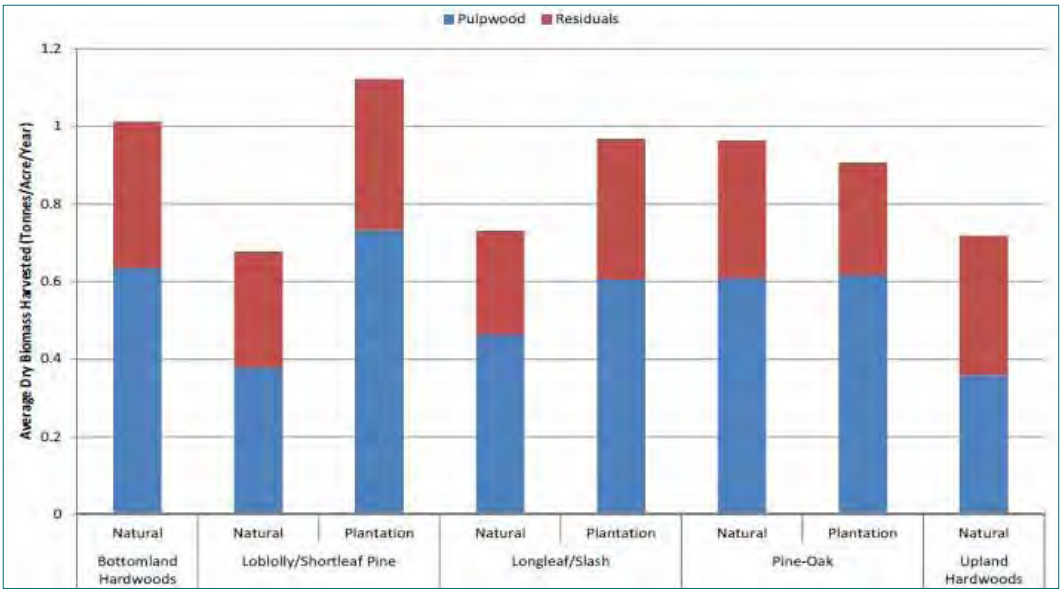
Results. The model design did not allow a direct comparison of natural stands versus plantations at the stand level, however, additional research indicated that converting from natural bottomland hardwoods to a loblolly pine plantation would have substantial negative carbon storage effects, and should probably be avoided. This could also be true for converting upland hardwoods. We also found that for a given acre, plantations can produce more biomass than natural stands over time. This may be a function of site productivity, improved genetic stock from planting, and silvicultural methods. For example, loblolly plantations produced considerably more biomass than natural upland hardwoods, but stored less carbon than upland hardwoods. This did not hold for the pine-oak forest types. The bottomland hardwoods, which are regenerated naturally, were highly productive second only to loblolly/shortleaf pine plantations. We did not find substantial GHG effects, however, at a regional scale.

Explanation. The model considers existing plantations at the study scale and was not designed to alter the amount of plantations nor the effects of converting natural stands to plantations, however, additional research was useful in providing information about the difference between natural stands and plantations. The average carbon stored over 100 years by forest type and stand origin is shown in Figure 29 on page 105. In general, the naturally regenerated hardwood types stored more carbon than softwood types. The baseline management, which assumes sawtimber and pulp production but not biomass, generally stored more carbon than when biomass management is added. There was not a clear pattern of carbon storage for the forest types that had both plantation and natural stand regeneration.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Figure 28.

Average biomass produced (harvested) over 100 years for the study area, by forest type, and stand origin.



In some forest types, plantations can grow more biomass than natural stands. This does not imply, however, that conversion of natural stands to plantations should occur to meet demand. The current placements of plantations were in response to economic and social choices in the past, which may not apply to existing natural stands since they represent different productive, ecological, and economic conditions. Naturally regenerated stands may also store more carbon while also producing substantial biomass feedstock as the bottomland hardwoods clearly show. Figure 29 on page 105 shows that in the forest types where plantations occurred, more than 50 percent of the area is already in plantations.

In areas where the pulp market has declined, biomass demand may provide a market for existing plantations. This would be beneficial to the atmosphere if the market prevented conversion from forest to other uses. Degraded natural stands could also benefit from a biomass market where improvement treatment costs could be offset by selling biomass.

Several additional elements would need to be added to this comparison to achieve accurate predictions of impacts to atmospheric carbon. These would include: harvest recovery technology, transportation distances and efficiencies, and biomass utilization efficiencies.

There is a general atmospheric carbon benefit associated with dense biomass recovery locations that are found in close proximity to efficient biomass facilities. In addition, sustainable forest management practices are a necessity to avoid a release in stored forest carbon. There are also examples where biomass utilization has made restoration efforts economically feasible. These elements should all be taken into consideration when prioritizing between natural stands and plantations.

It should also be noted that we are assuming all plantations harvested will be replanted. There may be instances when the landowner sells his plantation stands for biomass and then converts the land to development. Since we did not take into consideration land-use/ land-cover changes within the model, this carbon would not be recaptured and should be considered as an emission. Since forest carbon regeneration is a key component to landscape level GHG emissions; credit should be given only to areas where regeneration is an explicit part of the long-term management plan. Landholdings that are currently forested, and then are type converted into another non-forest land use (such as a development) should be explicitly excluded from regional GHG benefits assessments or quantified as a long-term emission.

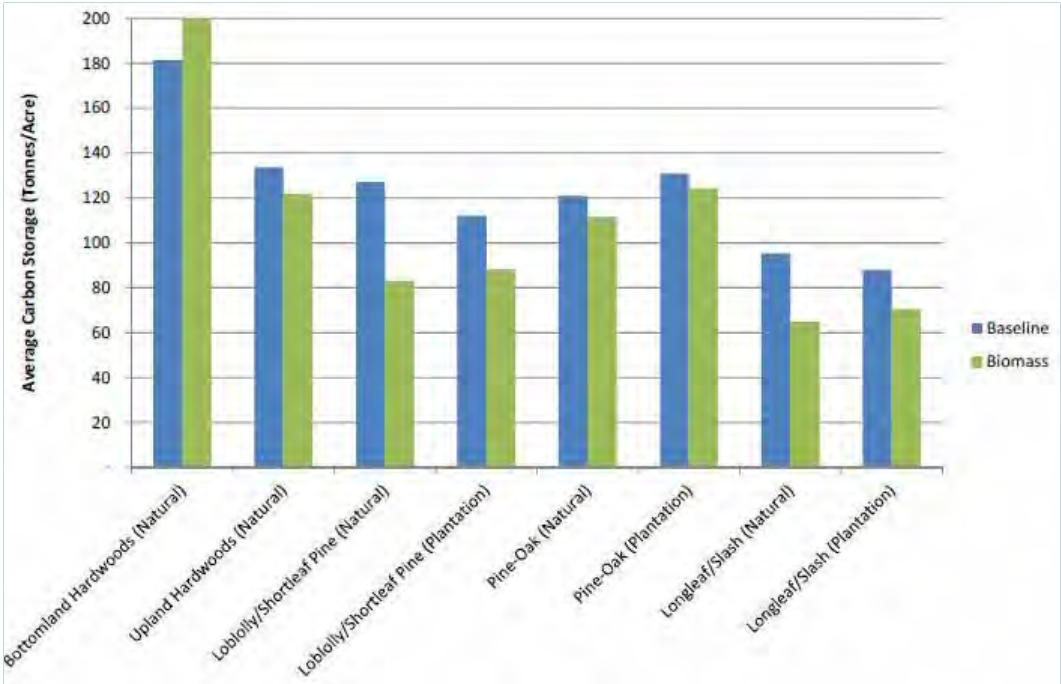


Figure 29.

Average carbon (CO_2) stored over 100 years for the study area, by forest type, stand origin, and management regime.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

7. What are the GHG consequences of varying levels of pellet export from the Southeast to Europe for electric power generation?

Results. The current biomass facilities and full build-out of currently proposed facilities scenario were not highly sensitive to the amount of wood pellets that were exported.

Explanation. A factor analyzed in our sensitivity analysis was the exporting of pellets. Our default setting was an assumption of 90 percent exports to Northern Europe. We also examined the effects of reducing the export of pellets to 40 percent.

Figure 30 below shows that reducing the export of pellets does not substantially improve the atmospheric carbon balance of using biomass for the proposed facilities. This is a factor of the relatively small atmospheric carbon cost of shipping pellets as ocean freight. It is important to note that the European Union (EU) is not accounting for the carbon emissions from burning wood pellets. Rather, the EU Emissions Trading System considers biomass resources to be carbon neutral and European industries are essentially getting a free pass on biomass carbon accounting. The wood pellet manufacturing, shipping, and combustion costs as well as the sequestration effects of wood products and in-forest carbon are all factors in a comprehensive carbon accounting.

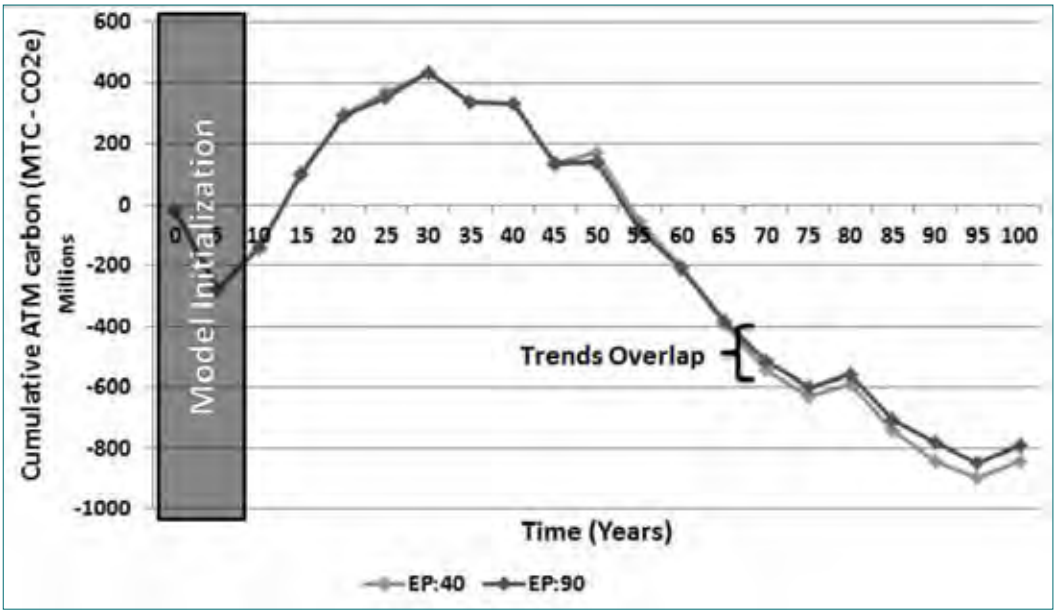


Figure 30.

Cumulative atmospheric carbon balance over 100 years using the 40% and 90% export options. Wood Supply Directly from the Forest (Forest Supply) at 50 percent and Wood Supply from Pulpwood (Pulp Supply) at 50 percent, and Wood Supply from Residuals (Non-Merchantable Supply) at 60 percent. The table is keyed in the following format: Export %.

8. Is there enough biomass available to supply 22 new biomass facilities while limiting the amount of residuals that can be removed to protect forest health?

Results. Although the sensitivity analysis did not indicate a significant change in carbon balance related to the amount of residuals allowed for removal, the analysis did indicate that limiting the amount of removal of residuals to either 30 or 60 percent of what is available after harvests did not present a limiting factor to supply at the scale and using the current model construct (see Figure 23 on page 96). This indicates that at least for the proposed additional capacity modeled, retaining sufficient residual biomass to maintain ecological health should not be limiting to biomass supply.

Explanation. There are physical, economic, and Best Management Practice limits to how much of the residuals (non-merchantable wood, bark, and foliage) can be removed from the forest. The results indicate that there is enough available material in other categories to fill a limitation on residual removal. The existing landscape, its current land use, existing markets, and energy demands provide a matrix where there is sufficient feedstock availability given the assumptions used in the analysis. Forest management practices that were used in this study reflect current methods. These methods could be improved upon to yield healthier forests and a more stable future feedstock for facilities that are scaled appropriately to the landscape that they serve. In short, there has to be sufficient activity on the landscape to produce the residuals or a difference will become apparent.

3.5.0 POLICY CHALLENGES: INCORPORATING FOREST BIOMASS AND CARBON MODELING INTO SOUND CLIMATE CHANGE POLICY

The Challenge of Evaluating Forest Carbon Flux

Recent studies at the Massachusetts Institute of Technology (MIT) reveal that participants from highly educated study groups repeatedly used flawed conceptual reasoning and violated fundamental physical principles when asked to anticipate the atmospheric effects of basic approaches to controlling carbon emissions (Sterman, 2008; Sterman 2007). People have difficulty conceptualizing flows of carbon stocks between different carbon pools such as forests and the atmosphere. Researchers confirm that the survey participants produce the wrong answer when they use a problem-solving approach called pattern matching to assume that an output of a system should look like its inputs. Researchers call this "stock-flow failure" (Cronin, 2009).

In the MIT studies, this stock-flow failure led people to believe that GHG accumulation in the atmosphere could be lowered merely by lowering the yearly emissions (Sterman, 2007). In other words, they believe that simply lowering the rate of emissions would lower the total stock of carbon in the atmosphere. In reality, however, GHG concentrations in the atmosphere can fall only when emissions drop below sequestration rates.

3. ATMOSPHERIC CARBON ANALYSIS *(cont'd)*

Furthermore, in the real world, time lags and movement between different types of carbon pools create complexities that create even greater challenges for those crafting climate change policy (Sterman, 2006). To assist readers in applying the results of this report and to assist the policy discussion, the following guideposts may be useful.

The Fundamental Cause of Long-Term Atmospheric Carbon Accumulation

Climate is changing due to increased levels of carbon in the atmosphere. Atmospheric carbon is increasing primarily because we burn fossil fuels and release carbon that was sequestered in geologic formations millions of years ago. Forest destruction and large-scale land-use change also increase atmospheric carbon. Forests and other carbon pools such as oceans, rocks and sediments, grasslands, or peatlands can sequester carbon but cannot absorb net increases in atmospheric carbon from combustion of fossil fuels or large-scale deforestation fast enough to be meaningful for environmental policy over the next few centuries. Forests re-sequester carbon relatively quickly but the worldwide forest pools cannot deal with the tremendous amount of carbon already released from both the fossil carbon pool and the forest carbon pool (31 gigatons in 2009) nor future releases from these pools (Henson, 2011). The full level of atmospheric carbon loading will eventually be determined by the total amount of carbon released from combustion of fossil fuels and conversion of forests to non-forest uses.

We have already added 300 gigatons of carbon pollution to the atmosphere over the last 150 years. The IPCC low-growth emissions scenario B1 anticipates the addition of another 700 gigatons. Regardless of final carbon levels, it is clear that it will take thousands of years for oceans, rocks and sediments, and terrestrial systems to reabsorb this carbon (Stager, 2011). This means that the effects of our current fossil fuel use will be felt by human beings and the earth's ecosystems for a long time. The management, harvest, destruction, and creation of forests will play a role in this situation, particularly in the short term, but over the long run, the story will be largely dictated by the total amount of fossil fuel carbon we release.

Acknowledging Long- and Short-Term Perspectives

The results of atmospheric life-cycle carbon assessments will prompt analysis from two different perspectives, both of which are necessary for development of effective climate policy. Those holding a long-term perspective will pay attention to the levels of atmospheric carbon that will be realized over centuries and millennia. The operative question for these long-term thinkers trying to determine the effects of atmospheric carbon on global climate is not how much we are emitting on a yearly basis (the flow) but what will be our total fossil fuel emissions (the stock) over time. Individuals with a long-term perspective will note that forest biomass is a biogenic source of energy and see the decades-long forest carbon debt and payback flux as relatively inconsequential in the long run—a mere short-term biogenic carbon flux in the context of the larger relatively permanent global geologic carbon flux.

Individuals with shorter-term perspectives will likely interpret the results of the current study differently and ask different questions. If there is a carbon emissions level policy target that is only decades away, then the use of more forest biomass may not help meet that specific short-term goal. A series of other questions will arise from the short-term perspective. What damaging climate events might be triggered through additional short-term carbon loading of the atmosphere? How do we weigh the short-term increase in carbon emissions from biomass against the larger longer-term benefits of substituting biomass for fossil fuels? How long will we utilize fossil fuels, when do we anticipate a total global switch to non-fossil alternatives, and how will the debt cycle of forest biomass overlap with that transition? Will an early emphasis on forest biomass help us transition to carbon-free alternatives like solar or wind or will it delay their implementation? Are there hidden ecological or carbon costs in the use of forest biomass of which we are not now aware?

Balancing Long- and Short-Term Perspectives

Two factors are critical to setting policy that balances the complicated short- and long-term flux dynamics of forest biomass. The first one is an estimate of when we can expect to transition fully away from fossil fuels. If this transition lies within the debt cycle of biomass systems, the policy response will be different than if the transition lies outside the debt cycle of biomass. In either case it should be realized that when full transition occurs that is also the point in time when biomass plants could theoretically be shut down and the forest allowed to recover and re-sequester the carbon that the biomass energy system has moved to the atmosphere while it was operating. (Of course this assumes that biomass harvesting is followed by forest regeneration and not the conversion of forest land to other uses.) An accounting and comparison to other alternatives could include this re-sequestration that would begin at this time.

The second factor pertains to the goals of climate policy—what policies are adopted to mitigate the effects of climate change to society and ecosystems. At some point in the future there will be an atmospheric carbon peak followed by a variety of physical global warming responses related to that peak. The warming will lead to climate events that will have repercussions on human society and natural ecosystems. Recognizing the linkages and timing of these events and matching them to the stocks and flows of forest carbon will be critical in setting the most effective policies.

The combustion of biomass for energy and subsequent release of carbon into the atmosphere is linked to a sequestration component when the material is produced from sustainably managed forests. Carbon is initially released as forests are harvested for biomass, and then re-sequestered over time as the forest recovers. This is unlike fossil fuels, which have no sequestration component. Biomass also has a longer payback period than other renewables such as wind and solar. Consequently, the carbon implications of biomass are much more difficult to decipher and prone to an endemic confusion over stocks and flows. It is neither immediately carbon neutral, nor can the payback periods be summarily dismissed as unhelpful to climate goals. Therefore, biomass deserves a full and comprehensive discussion of its potential to help meet climate change goals through close attention to proper GHG accounting methodologies.

CONCLUSIONS

OVERALL

This study confirms that the life-cycle carbon implications of biomass when used for energy production are complex and do not lend themselves to simple or blanket public policy options. It is important to remember that the results in this study apply only to an analysis of biomass electric power and electric-led CHP in a specific region of the southeastern United States. It does not apply to thermal-energy pathways as these have significantly higher efficiencies and consequently different carbon life-cycle analyses. Nor does it directly apply to other regions with different forest types, utilization trends, or market conditions.

Forestry and forest management have long been involved with the sustainable production of wood fiber for use by society. The production of wood fiber for biomass energy affects the carbon exchange between the biosphere and atmosphere. By accurately accounting for this exchange through a full life cycle carbon analysis, this study illustrates how utilizing our forests for biomass energy can affect yearly emissions and the eventual accumulation of green house gases in the atmosphere when compared to using fossil fuels. The manipulation of important parameters in the model also allow us to test which policy and forest management decisions may create a more or less positive outcome for the use of biomass. These results can be combined with other factors, such as a weighing of short and long term carbon accumulation in regard to damaging climate events or the ecological effects of harvesting more biomass to inform policy and management decisions.

WOOD SUPPLY

- Most studies conducted in the past six years quantify the gross or total amount of woody biomass material generated on an annual basis and do not quantify how much is already being used. Most of these studies focus on residues produced from other primary activities while evidence suggests nearly all the mill and urban wood residues are already used by existing markets.
- The evidence clearly suggests that any expanded biomass energy in the Southeast will come from harvested wood (either tops and limbs left behind from timber harvesting, whole trees, or pulpwood sourced from the main stem of a harvested tree).
- Whether logging slash, whole trees, or pulpwood will be used in the expansion of biomass energy in the Southeast will depend on:
  1. Which market the wood is going to (pellet mills need high-quality fiber from pulpwood while biomass plants are less particular about quality)
  2. How much demand increases within the pellet and power market sectors over time
  3. What happens with the pulp and paper industry in the southeast region in the future
- Prior to 2009, most fuel availability studies presented estimates of supply without any acknowledgment of the influence price has on the availability of these woody biomass resources. Since then, different studies have examined the economics using different indicators, making it

difficult to compare results between the studies. For a clear assessment of the economics of woody biomass resources, the total delivered price paid by the receiving facilities is the best indicator to use.

- Various studies reviewed in this chapter used widely divergent assumptions regarding what percentage of the total amount of logging residue can be recovered from a harvested area. While the range observed in the literature was from roughly 50-100 percent, it should be noted that there is a difference between how much residue *can* be recovered and how much *should* be recovered when ecological factors are taken into account. While examining how much wood fuel could be generated if 100 percent of this material was recovered is useful for academic purposes, it is unrealistic to assume that such a high level can and should be realized. Ideally, studies would look at two critical issues when factoring the overall recovery rate—percentage of recovered residues on individual harvest operations and percentage of harvest operations where residues can be recovered.
- The availability of logging residues will largely depend on extraction methods. Where whole-tree harvesting systems can be used, these residues can be cost-effectively accessed, however, the ecological effects of whole-tree logging need to be considered. Where mechanized cut-to-length and manual stem-only harvesting are used, these residues will not be easily accessible. Further analysis that determines how much whole-tree harvesting systems versus stem-only harvesting systems are used across this region would be very useful.
- Of all the states in the seven-state study region, North Carolina has had the most in-depth and sophisticated level of study of its biomass energy potential. In contrast, Alabama and Tennessee both had very little publicly available reports estimating biomass resources.
- Evidence suggests that there is likely enough wood to meet a 15 percent federal RES standard applied to each of the seven states (with the exception of Florida) when woody biomass sourced from local forests accounts for no more than 20 percent of the overall renewable electric generation target. It also appears, however, that adequate wood fuel resources are quite sensitive to the RES allocation. For example, if 30 percent of a 15 percent RES was allocated to forest biomass, it is likely there would not be enough wood fuel available within the region. A more aggressive RES standard for biomass leads to a higher likelihood of shortages and a greater probability of pulpwood displacement.
- Capacity to access and utilize residues is also a function of how much roundwood harvest occurs. More demand for roundwood generates more residues. The extent to which biomass power plants transition their wood procurement away from residues and toward roundwood is governed by the strength of the rest of the forest products industry. If the forest products industry strengthens as a result of greater lumber demand, it will increase its wood fiber consumption and, as a result, biomass power plants would procure more residues at a lower cost and less pulpwood at a higher cost. If the forest products industry as a whole continues to contract, however, biomass power plants will likely transition toward procurement of chipped fuel from whole trees *assuming* they can absorb the higher cost associated with that transition.

  While some believe that biomass power demand will likely transition to procuring roundwood and displacing wood from

CONCLUSIONS *(cont'd)*

the pulp and paper industry, it is actually more likely that growth in pellet markets—which demand higher-fiber quality found in roundwood (not slash)—will be the market that most immediately displaces pulpwood. Therefore, pellet mills and biomass power plants have somewhat complementary (almost symbiotic) procurement needs. Pellet production, especially the export market to Europe, will continue to play the wildcard role in future wood fuel markets.

- The potential recovery rate for harvest residue is a key variable in determining the quantity of available wood fuel. Further research is needed to assess both the current achievable residue recovery rates and reasonable future recovery rates. Projected recovery rates need to consider woody biomass retention rates to meet wildlife and biodiversity, water quality, and soil productivity needs.
- The supply chapter undertakes a hypothetical exercise looking at current forest growth rates versus current removals to generate some rough estimates of the state and regional potential woody biomass supply for energy. This exercise suggests that meeting 20 percent of a 15 percent renewable electricity standard with woody biomass would be possible in the Southeast region. Meeting 30 percent of a 15 percent RES would likely exceed the projected supply. This exercise points out that there are distinct limits on how far woody biomass supply in the region can go toward meeting renewable energy targets.

CARBON LIFE-CYCLE ANALYSIS

The conclusions provided here are grouped to track with the key questions the study is intended to address.

What are the atmospheric carbon implications of operating the existing 17 biomass power plants in the study region versus not running them into the future and using fossil fuel instead?

Our findings indicate that the 17 existing biomass facilities (149 MW and 1.755 million tons of pellets) now generate and would continue to generate an improved atmospheric carbon balance relative to fossil fuels to provide equivalent power. Continuing to run these existing 17 biomass power plants would result in lower atmospheric carbon in the short- and long-term than shutting them down and shifting to fossil fuels.

What are the atmospheric carbon implications of operating the existing 17 biomass power plants as compared to operating these existing plants plus 22 new proposed biomass power plants?

Answering this includes a range of sensitivity analyses, including the impacts of varying the proportions of residuals versus pulpwood and natural forests versus plantations.

Additional biomass facilities produced long-term atmospheric carbon benefits for a short-term atmospheric carbon cost. The biomass option recovered the carbon debt in 35-50 years depending on the fossil fuel scenarios being compared.

What are the GHG consequences of varying the amounts of biomass required to make a specific amount of electricity?

Biomass utilization per unit of power produced is a factor and can alter the outcome of the atmospheric carbon balance over time. We showed that a lower assumption of biomass demand per unit of power produced shortened the payback period relative to the other fuels and pathways. There are a range of values associated with how much biomass is required to produce a given amount of electricity. Using a mid-range target of 6,800 BDT per MW per hour per year provided the payback period of 35-50 years.

What are the GHG consequences of using forest derived biomass (tops, limbs, pulpwood) versus non-forest derived biomass (mill wastes and urban tree thinning)?

The forest supply sensitivity analysis did not show a substantial difference for the scenarios modeled at the landscape scale. The study does show that using non-forest biomass generally has a slightly lower atmospheric carbon profile. These results were surprising. A much larger benefit from using non-forest biomass feedstocks was expected considering that this biomass has lower processing and transportation emissions as well as avoided decomposition emissions benefits. What we found was, at the regional scale, there were no significant differences in landscape level GHG accumulation because the integrated carbon profiles of the different feedstocks were similar to one another (the net magnitude of emissions between the processing, transportation, and avoided decomposition were similar, Figure 25).

What are the GHG consequences of using tops and limbs (residuals) for biomass supply versus pulpwood (main stems)?

The forest supply sensitivity analysis did not cause a substantial difference for most of the scenarios modeled at the landscape scale. This result, however, needs to be considered in the context of the model. The use of residuals versus main stems would reduce atmospheric carbon accumulation in those situations where there are adequate amounts of residuals available from current harvests. This result is based on the higher relative future carbon storage of pulpwood versus residuals. This general rule also holds true for situations where no pulp market exists and standing trees might be left to grow and sequester carbon. Since residuals are not the driver of timber harvests, however, when a landscape model is asked to service biomass facilities only from residuals and the required amount of residuals is not readily available from existing timber harvests, it causes more acres to be harvested. Thus, when this model was instructed to supply the 22 new facilities with only residuals, it had to include more acres of overall harvest to generate these residuals and consequently did not cause a substantial difference in the GHG consequences versus pulpwood.

An accurate depiction of the pulpwood versus residual utilization comparison requires a spatially specific and market-dependent analysis beyond the scope of this study. Such a study would incorporate different market scenarios that would influence the carbon emissions such as: active sawtimber market, active sawtimber and pulp market, no markets, and active pulp market.

CONCLUSIONS *(cont'd)*

What are the GHG consequences of using natural stands versus plantations to fuel an expansion of biomass electric power in the Southeast?

The model design did not allow a direct comparison of natural stands versus plantations at the stand level. Additional research, however, indicated that converting from natural bottomland hardwoods to a loblolly pine plantation would have substantial negative carbon storage effects, and should probably be avoided. This could also potentially be true for upland hardwoods. We also found that for a given acre, plantations can produce more biomass than natural stands over time. This may be a function of site productivity, improved genetic stock from planting, and silvicultural methods. This did not hold for the pine-oak forest types. The bottomland hardwoods, which are regenerated naturally, were highly productive second only to loblolly/shortleaf pine plantations. Nevertheless, we did not find substantial GHG effects at a regional scale.

What are the GHG consequences of varying levels of pellet export to Europe for electric power generation from the Southeast?

The current biomass facilities and full build-out scenario were not highly sensitive to the amount of wood pellets that were exported and did not improve significantly as more pellets were consumed domestically.

Is there enough biomass available to supply 22 new biomass facilities while limiting the amount of residuals that can be removed to protect forest health?

Limiting residual amount removal to either 30 or 60 percent of what is available after harvests did not present a limiting factor to supply using the current model construct. This indicates that at least for the proposed additional capacity modeled, retaining sufficient residual biomass to maintain ecological health should not be limiting to biomass supply. We did not find a significant GHG affect when the amount of residuals removed was varied.

POLICY IMPLICATIONS

This analysis of using forest biomass to supply electric power generation in the Southeast replicates the multi-decade payback pattern from similar studies that integrate life-cycle carbon accounting with forest carbon accounting. This pattern remained consistent even though this study incorporated more accurate harvest regimes, operated in a region with an active pulp market, and examined specific woodsheds and facility placement as compared to other recent forest carbon modeling work. This suggests that the leading factor in the long payback periods is the low efficiency of power generation and not forest harvest or growth variables or regional forest types. Similar studies in other regions will be necessary to confirm this.

The multi-decade debt and payback periods for biomass power reinforce the benefits of using biomass for more efficient heating or cooling applications or CHP applications in regions where appropriate. It suggests a policy of prioritization for the use of forest biomass that focuses first on thermal applications where possible and appropriate and then on power applications.

Interpreting these multi-decade payback results in terms of long- and short-term climate change goals requires a deeper policy discussion than has yet occurred. Regulating atmospheric carbon for climate change goals requires sophisticated carbon stock-flow accounting—a dynamic that is not intuitively easy for the public to understand. Interjecting biomass into this accounting magnifies the challenge because the use of biomass for energy, unlike fossil fuels, comes associated with a sequestration component that must be accounted for over time. Effort should be made to more clearly represent this accounting for greater understanding and to avoid unintended faulty policy decisions.

For example, interpreting these results by relating them strictly to yearly emission targets at some specified point in time would be inaccurate as it fails to account for the eventual payback. The results of this study should prompt a closer evaluation of the short-term costs and long-term benefits and relate them to actual atmospheric carbon accumulations and climate change goals over a timeframe appropriate to the future trends of climate change.

Depending on the importance assigned to long-term benefits and short-term debt, the prospect of adding 22 new generating or pellet facilities may look favorable or unfavorable for climate goals. The carbon storage capacity of natural forests indicates it may be harmful to convert natural forest to plantations for carbon benefits even though plantations may out-produce natural stands in some situations (and this practice would have other serious ecological consequences that must be considered as well). The use of residuals, where available, would provide greater carbon benefits, however, since intensive removals of residuals could result in negative ecological impacts, the study examined the results from limiting the removals and determined there would still be adequate supply for the facilities that were modeled.

This study can be useful for policy development involving programs with incentives for biomass production and regulatory efforts. It is most readily adaptable for programs involving incentives as it allows different policy approaches to be compared and evaluated in relation to one another. The data provide a relative difference among approaches that may facilitate the ranking of different technologies for their support of climate goals and an assignment of different levels of incentives to different technologies.

CONCLUSIONS *(cont'd)*

This study may also be helpful for regulatory mechanisms. It offers EPA additional information to develop an appropriate framework for accounting for the emissions of biogenic carbon from stationary sources. In EPA's September 2011 report, it selected a "reference-point" approach for setting a baseline although it acknowledged the benefits of using the "comparative" approach used in this study. The EPA report championed the "reference-point" approach because it was "straightforward" and met a list of criteria, including ease of use, ease of understanding, and accuracy in prediction of carbon outcomes. The "reference point" predicts if the system has more or less carbon stored at the end of the assessment period than at the beginning while the "comparative" approach determines if there is more or less carbon than there would have been if the energy was created by fuel sources other than biomass. This study provides an example of how the "comparative" approach can be used for a specific region. It can be further evaluated by EPA to see if it meets its criteria and is useful for developing regulations.

The carbon accounting linkage between the source of the emission and the forest means that the potential of biomass as a renewable fuel is directly connected to the future of forest management. The development of biomass markets can have positive or negative effects on forest management and, conversely, the types of forest management practiced in the future will directly affect carbon payback periods. The sensitivity analysis from this study and results from other studies indicate that payback periods for biomass can vary widely depending on critical variables.

This suggests that a more comprehensive, sophisticated, and targeted approach for biomass policy that includes forest management could produce shorter payback periods and greater climate change benefits. Some potential policy targets include the following.

More Efficient Technologies

Use of biomass for thermal and CHP applications yield far shorter payback periods and greater benefits than power generation. Thermal and CHP applications can be 70-80 percent efficient while biomass power is only 25 percent efficient. Where appropriate, policy can direct forest biomass for use in these applications.

Smaller-Scale Applications

Smaller-scale heat or CHP applications can minimize transportation costs and target localized forest supply from forest situations that yield a shorter payback period. For example, localized supply of downed material or fire-prone material destined for quick carbon release to the atmosphere might show favorable payback periods if used to displace fossil fuel use for production of efficient thermal energy.

Enhanced Ecosystem Services

Biomass markets that allow forest improvement practices to protect water quality or increase carbon sequestration may improve ecosystem services that have an accompanying carbon benefit, thus lowering payback periods.

Improved Forest Management

Necessary forest-restoration work, perhaps to shift forest types to better adapted species or conduct pre-commercial thinnings, can be facilitated by biomass markets. The improved forestry can yield more forest products that offset other, more carbon-intensive products or increased revenue yields that help landowners keep forests as forests.

This study focuses on the carbon implications of increased biomass use and does not deal directly with other ecological impacts. Any policy encouraging the increased use of biomass must also account for effects on ecological values of the forest and should enhance the quality of forest management. The study results indicate a lowering of the average amount of carbon in the forest as compared to not harvesting these forests for biomass. More information is needed to fully evaluate the effects of lower carbon levels on wildlife and forest systems dynamics, including soil and water quality. An extension of best management practices to include biomass retention and harvesting guidelines is recommended. The Forest Guild has completed a set of retention and harvesting guidelines for the Northeast and is due to release a similar report for the Southeast by the end of this year.

ENDNOTES

[1] Disclaimer: We did not address agricultural residues such as corn stover, wheat straw, or manure. Furthermore, the study did not factor spent black liquor from pulping, bio-solids from waste-water treatment plants, or landfill gas, even though these materials may be vital resources that could contribute toward achieving target amounts of biomass energy in the RPSs.

[2] During the course of the literature search, numerous presentations and testimonies were found on-line and many of these presentations contained helpful information. However, these sources were not directly included as part of our literature review and critique because it is often very easy to take information contained in PowerPoint presentations out of context and misinterpret the meaning.

[3] Chip prices are for residual chips delivered to pulpmills and do not reflect the prices of chips sourced from chipmills.

[4] These model runs employed different rates of harvest residue utilization reaching upward to 85% over time.

[5] This technical potential estimate uses 85% harvest residue recovery rate for softwoods and 70% for hardwoods. These recovery rates are generally considered to be on the high end of the range of what is viable.

[6] It should also be noted that this resource assessment not only included North Carolina but also border counties of Virginia and South Carolina counties that fall within Duke or Progressive Energy's service territories.

[7] Based on the assumption of a 50% harvest residue recovery rate.

[8] Consistent but not necessarily the most accurate! While different studies may have presented more recent estimates using more sophisticated methods, these studies did not address all seven of the states and so a single data source providing "wall-to-wall" coverage was necessary.

[9] In-growth (new trees) + Accretion (growth of existing trees) – Mortality (natural death) = Net growth

[10] All data obtained from published FIA factsheets for each of the seven states.

[11] This information on inventory comes from the USDA Forest Service's Forest Inventory and Analysis (FIA) program, which generates reliable estimates of the condition and health of the forest resource and how it is changing over time. The program uses a statistically designed sampling method to select hundreds of plots for measurement by field crews and includes plots that were counted in previous inventories. The re-measurements on the same plots yield valuable information on how individual trees grow. Field crews also collect data on the number, size, and species of trees, and the related forest attributes.

[12] Data for Total Inventory is for growing stock volume. Growing stock is the traditionally merchantable wood contained in live trees greater than five inches.

[13] The amount of wood derived from trees that would be otherwise used by Virginia lumber and pulp manufacturers is capped at 1.5 million green tons annually.

[14] Note that each year's percentage requirement refers to the previous year's electricity sales (i.e., the 2021 standard is 12.5% of 2020 retail sales).

[15] Other Renewables includes biogenic municipal solid waste, wood, black liquor, other wood waste, landfill gas, sludge waste, agriculture byproducts, other biomass, geothermal, solar thermal, photovoltaic energy, and wind.

[16] Other gases includes blast furnace gas, propane gas, and other manufactured and waste gases derived from fossil fuels.

[17] Other includes non-biogenic municipal solid waste, batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, tire-derived fuels and miscellaneous technologies.

[18] MW electric produces approximately 136 MMBtu/hr of heat. Residential heating typically uses 40 Btu's/sq ft. Based on a 3,000 square foot house, heating requirement is 120,000 Btu's/hr, or 1,137 homes.

[19] Graph information is derived from Appendix A. See that Appendix for data and sources.

[20] Chart information is derived from Appendix A. See that Appendix for sources.

[21] Graph information is derived from Appendix A. See that Appendix for data and sources.

[22] Chart information is derived from Appendix A. See that Appendix for sources.

[23] Graph information is derived from Appendix A. See that Appendix for data and sources.

[24] Chart information is derived from Appendix A. See that Appendix for sources.

[25] Graph information is derived from Appendix A. See that Appendix for data and sources.

[26] Chart information is derived from Appendix A. See that Appendix for sources.

[27] Graph information is derived from Appendix A. See that Appendix for sources.

[28] Chart information is derived from Appendix A. See that Appendix for sources.

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APPENDICES

A. Technology Pathways Database

B. Forest Growth Simulation

Appendix A

TECHNOLOGY PATHWAYS SUMMARY

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	p	Q	R	S	T	U	V	W	Z	Y	Z	AA	AB
1																												
2								(F)*(H)*3.412			(J)/(K)		(M)/(N)	(O)/(J)	(O)*3.6667/(M)	(J)*(U)/M	(Q)+(R)	(Q)*(M)/(J)		(T) + (U)		(W)*(M)/(J)	(Q)/3.6667	(R)/3.6667	(Y)+(Z)	(T)/3.6667	(U)/3.6667	(AB)+(AC)
3	1 Exisiting woody biomass	Electricity		20	MW	8,760	100%	597,782	25.6%	25.6%	2,335,088	8,500	137,358	459.56	215.7	4.2	219.9	842.5	16.5	859.1	0.007054	0.0276	58.8230	1.1555	59.9785	229.7775	4.513481829	234.2910
4	power plants											(btu/lb)																
5	2 New woody biomass	Electricity		50	MW	8,760	100%	1,494,456	28.2%	28.2%	5,307,017	8,500	312,177	417.78	215.7	4.7	220.3	765.9	16.5	782.5	0.007054	0.0250	58.8230	1.2710	60.0940	208.8887	4.513481829	213.4021
6	power plants											(btu/lb)																
7	2A Pellet exportation	Electricity		50	MW	8,760	100%	1,494,456	28.2%	28.2%	5,307,017	8,500	312,177	417.78	215.7	68.8	284.5	765.9	244.4	1010.3	0.007054	0.0250	58.8230	18.7691	77.5922	208.8887	66.65164706	275.5403
8	(European power plants)																											
9	3 Co-firing power plants	Electricity		450	MW	8,760	100%	13,450,104	32.3%	32.3%	5,253,947	8,500	309,056	45.96	215.7	0.4	216.1	84.3	1.7	85.9	0.007054	0.0028	58.8230	0.1155	58.9386	22.9778	0.451348183	23.4291
10	90% coal									(coal)	37,523,539	12,500	1,500,942	223.19	205.3	6.2	211.5	572.8	19.2	591.9	0.003306	0.0092	55.9904	1.6849	57.6753	156.2038	5.222743259	161.4266
11	10% woody biomass										42,777,486	12,100	1,809,997	269.14	206	6.6	212.9	656.3	20.8	677.1	0.003681	0.0117	56.2737	1.8004	58.0741	178.9760	5.674091442	184.6501
12																												
13	4 Woody biomass	Electricity		5	MW	8,760	100%	398,026	75.0%	28.2%	530,702	8,500	31,218	156.86	215.7	6.1	221.7	287.6	8.1	295.6	0.007054	0.0094	58.8230	1.6500	60.4730	78.4307	2.2	80.6307
14	CHP		Thermal	248,581	MMBtu							(btu/lb)																
15			Electrical	149,446	MMBtu																							
16	5 Switchgrass			50	MW	8,760	100%	1,494,456	28.2%	28.2%	5,307,017	7,200	368,543	493.21	229.2	4.7	233.8	813.8	16.5	830.4	0.007054	0.0250	62.4995	1.2710	63.7705	221.9442	4.513481829	226.4577
17	power plants											(btu/lb)																
18	6 Co-firing power plants	Electricity		450	MW	8,760	100%	13,450,104	32.5%	32.5%	4,776,315	7,200	331,689	49.32	229.2	0.5	229.6	81.4	1.7	83.0	0.007054	0.0025	62.4995	0.1271	62.6266	22.1944	0.451348183	22.6458
19	90% coal									(coal)	37,228,114	12,500	1,489,125	221.43	205.3	6.2	211.5	568.2	19.2	587.4	0.003306	0.0092	55.9904	1.6982	57.6886	154.9740	5.222743259	160.1968
20	10% switchgrass										42,004,430	11,970	1,820,813	270.75	208	6.7	214.4	648.6	20.8	669.4	0.003681	0.0115	56.6413	1.8253	58.4666	176.8898	5.674091442	182.5639
21																												
22	7 Switchgrass	Electricity		5	MW	8,760	100%	398,026	75.0%	28.2%	530,702	7,200	36,854	185.19	229.2	6.1	235.2	305.6	8.1	313.6	0.007054	0.0094	62.4995	1.6500	64.1495	83.3327	2.2	85.5327
23	CHP		Thermal	248,581	MMBtu							(btu/lb)																
24			Electrical	149,446	MMBtu																							
25	8 Existing coal	Electricity		450	MW	8,760	100%	13,450,104	33.0%	33.0%	40,757,891	12,500	1,630,316	242.42	205.3	7.0	212.3	622.1	21.3	643.4	0.003306	0.0100	55.9904	1.9150	57.9054	169.6679	5.803048066	175.4709
26	power plants											(btu/lb)																
27	9 New coal	Electricity		600	MW	8,760	100%	17,933,472	36.3%	36.3%	49,403,504	12,500	1,976,140	220.39	205.3	7.7	213.0	565.6	21.3	586.8	0.003306	0.0091	55.9904	2.1065	58.0969	154.2435	5.803048066	160.0466
28	power plants											(btu/lb)																
29	10 Coal	Electricity		5	MW	8,760	100%	339,649	75.0%	33.0%	452,865	12,500	18,115	106.67	205.3	16.0	221.3	273.7	21.3	295.0	0.003306	0.0044	55.9904	4.3523	60.3427	74.6539	5.803048066	80.4569
30	CHP		Thermal	190,203	MMBtu							(btu/lb)																
31			Electrical	149,446	MMBtu																							
32	11 New natural gas			800	MW	8,760	100%	23,911,296	42.0%	42.0%	56,931,657	102,800	553,809,894	23.16	117.0	33.8	150.8	278.6	80.4	359.0	0.00022	0.0005	31.9088	9.2075	41.1163	75.9733	21.92262603	97.8960
33	power plants											(btu/therm	therms	therms/MMBtu														

Grey cells are estimates

Blue cells are sourced figures

Green cells are calculations

D3	Average capacity of exisiting biomass plants in seven-state study region - cta.ornl.gov/bedb/biopower/Current_Biomass_Power_Plants.xls
D5, D14, D21	Average capacity of existing coal plants in seven-state study region http://www.eia.gov/electricity/data.cfm#gencapacity By Energy Source, by Producer, by State (EIA-860)XLS
D9, D18, D25	Estimate of likely size of thermal-led CHP projects feasible in seven-state study region
D23	Average capacity of coal plants constructed in seven-state study region since 2000 - http://www.eia.gov/cneaf/electricity/page/capacity/existingunits2008.xls
G3, G21, G23, G28	Average capacity factors for electrical generation plants - http://www.eia.gov/oiaf/aeo/pdf/2016levelized_costs_aeo2011.pdf
G9, G18, G25	Average capacity factor of CHP plants estimateded to be 10% lower than electrical only generation
G5, G14	Capacity factors for co-firing assumed to be the same as coal
G13	Average capacity factor of switchgrass plants assumed to be the same as woody biomass
I3, I9	Efficiencies of biomass electrical and CHP plants from IEA - Energy Technology Essentials
I21, I28	Efficiencies of coal and natural gas from EIA - Electric Power Annual 2009Released: November 23, 2011
I12, I18	Efficiencies of switchgrass plants assumed to be the same as biomass plants
J	Electrical efficiency of CHP plants assumed to be 10% lower than electrical-only effiencieny for that fuel type due to projected efficiency losses in process of heat recovery
L2, L5, L9	Assumes 0% moisture content ("bone-dry") - cta.ornl.gov/.../The_Effect_of_Moisture_Content_on_Wood_Heat_Content. Xls
L6, L15, L21, L23, L25	EIA Heating Fuel Comparison Calculator - http://www.eia.gov/neic/experts/heatcalc.xls
L12, L14, L18	Assumes 0% moisture content - Forest Product Lab Fuel Value Calculator - http://www.fpl.fs.fed.us/documnts/techline/fuel-value-calculator.pdf
O2, O5, O9	Assumes wood is 50% carbon by weight - Economics and Carbon Offset Potential of Biomass Fuels - REAP - Canada
O12, O14, O18	Assumes switchgrass is 45% carbon by weight - Economics and Carbon Offset Potential of Biomass Fuels - REAP - Canada
O6, O14, O21, O23, O25, O28	Voluntary Reporting of Greenhouse Gases Program Fuel Emissions Coefficients - http://www.eia.gov/oiaf/1605/coefficients.html
Q	Voluntary Reporting of Greenhouse Gases Program Fuel Emissions Coefficients - http://www.eia.gov/oiaf/1605/coefficients.html

Appendix B. Forest Growth Simulation.

This appendix contains information related to the forest growth, mortality and harvest simulations.

Table B-1. Prescriptions used in eco-section 2311 (Central Appalachian Piedmont) for forest and regeneration types, by site class and biomass utilization. Treatment codes with associated metrics are: N=Natural regeneration in trees per acre; P=Planted in trees per acre; F-Fertilized; STS=Single Tree Selection to residual basal area (sq ft/ac); H=Herbicide treatment of competing vegetation; PT=Pre-commercial Thin to percent volume; TH=Thin from below to residual basal area (sq ft/ac); CC=Clearcut.

					Age																													
		Site (50-yr)			0		5		10		15		20		25		30		35		40		45		50		55		60		65		70	
Type	Regen	Class	Index	Biomass	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric
Loblolly/Shortleaf	Natural	Low	74	No	N										TH	80					CC													
		High	90	No	N								TH	80					CC															
		Low	74	Yes	N						PT	65%V			TH	80					CC													
		High	90	Yes	N				PT	65%V			TH	80					CC															
	Planted	Low	80	No	P,F	500	H						TH	80			TH	70			CC													
		High	102	No	P,F	550	H				TH	90			TH	70			CC															
		Low	80	Yes	P,F	700	H		PT	60%V			TH	80			TH	70			CC													
		High	102	Yes	P,F	700	H		PT	70%V	TH	90			TH	70			CC															
Pine-Oak	Natural	Low	75	No	N																												CC	
		High	94	No	N																										CC			
		Low	75	Yes	N												TH	60															CC	
		High	94	Yes	N										TH	60															CC			
Upland Hardwood	Natural	Low	78	No	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High	102	No	N																		STS	70							CC			
		Low	78	Yes	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High	102	Yes	N								TH	50									STS	70							CC			
Bottomland Hardwood	Natural	Low	86	No	N										TH	80									CC									
		High	116	No	N										TH	80							CC											
		Low	86	Yes	N						TH8	0					TH6	0							CC									
		High	116	Yes	N								TH	70			TH	50					CC											

Table B-2. Prescriptions used in eco-sections 232C (Atlantic Coastal Flatwoods) and 232J (Southern Atlantic Coastal Plains and Flatwoods) for forest and regeneration types, by site class and biomass utilization. Treatment codes with associated metrics are: N=Natural regeneration in trees per acre; P=Planted in trees per acre; B=broadcast burn; F-Fertilized; STS=Single Tree Selection to residual basal area (sq ft/ac); H=Herbicide treatment of competing vegetation; PT=Pre-commercial Thin to percent volume; TH=Thin from below to either residual basal area (sq ft/ac) or trees per acre (p=pine, h=hardwoods); CC=Clearcut.

					Age																													
		Site (50-yr)			0		5		10		15		20		25		30		35		40		45		50		55		60		65		70	
Type	Regen	Class	Index	Biomass	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric
Loblolly/Shortleaf	Natural	Low		No	N								TH	70			TH	60			CC													
		High		No	N						TH	85			TH	75			CC															
		Low		Yes	N		PT	400					TH	65			TH	60			CC													
		High		Yes	N		PT	450			TH	75			TH	75			CC															
	Planted	Low		No	P,F	550					TH	70			TH	60			CC															
		High		No	P,F	550					TH	80	TH	80			CC																	
		Low		Yes	P,F	550			PT	400			TH	65			TH	60	CC															
		High		Yes	P,F	550			PT	400	TH	80	TH	80			CC																	
Longleaf/Slash	Natural	Low		No	B,N								TH	70			TH	60			CC													
		High		No	B,N						TH	85			TH	75			CC															
		Low		Yes	B,N		PT	400					TH	65			TH	60			CC													
		High		Yes	B,N		PT	450			TH	75			TH	75			CC															
	Planted	Low		No	P,F	550					TH	70			TH	60			CC															
		High		No	P,F	550					TH	80	TH	80			CC																	
		Low		Yes	P,F	550			PT	400			TH	65			TH	60	CC															
		High		Yes	P,F	550			PT	400	TH	80	TH	80			CC																	
Pine-Oak	Natural	Low		No	N										TH	65p/50h					CC													
		High		No	N								TH	50p/50h			TH	45p/45h			CC													
		Low		Yes	N						TH	350p/200h			TH	70					CC													
		High		Yes	N								TH	50p/50h			TH	45p/45h			CC													
Upland Hardwood	Natural	Low		No	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		No	N										CT	80					STS	50			STS	30					CC			
		Low		Yes	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		Yes	N								TH	70					STS	50			STS	30							CC			
Bottomland Hardwood	Natural	Low		No	N										TH	80									CC									
		High		No	N										TH	80							CC											
		Low		Yes	N								TH	65					TH	80					CC									
		High		Yes	N								TH	70					TH	80			CC											

Table B-3. Prescriptions used in eco-section 232B (Gulf Coastal Plains and Flatwoods) for forest and regeneration types, by site class and biomass utilization. Treatment codes with associated metrics are: N=Natural regeneration in trees per acre; P=Planted in trees per acre; B=broadcast burn; F-Fertilized; STS=Single Tree Selection to residual basal area (sq ft/ac); H=Herbicide treatment of competing vegetation; PT=Pre-commercial Thin to percent volume; TH=Thin from below to either residual basal area (sq ft/ac) or trees per acre (p=pine, h=hardwoods); CC=Clearcut.

					Age																													
		Site (50-yr)			0		5		10		15		20		25		30		354		04		55		05		56		0		65		70	
Type	Regen	Class	Index	Biomass	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric	Treat	Metric
Loblolly/Shortleaf	Natural	Low		No	N								TH	70			TH	60			CC													
		High		No	N						TH	85	T		H	75	C		C															
		Low		Yes	N		PT	400					TH	65			TH	60			CC													
		High		Yes	N		PT	450			TH	75	T		H	75	C		C															
	Planted	Low		No	P,F	550					TH	70			TH	60			CC															
		High		No	P,F	550					TH	80	TH	80			CC																	
		Low		Yes	P,F	550	PT	400					TH	65			TH	60	CC															
		High		Yes	P,F	550	PT	400			TH	80	TH	80			CC																	
Longleaf/Slash	Natural	Low		No	B,N								TH	70			TH	60			CC													
		High		No	B,N						TH	85	T		H	75	C		C															
		Low		Yes	B,N		PT	400					TH	65			TH	60			CC													
		High		Yes	B,N		PT	450			TH	75	T		H	75	C		C															
	Planted	Low		No	P,F	550					TH	70			TH	60			CC															
		High		No	P,F	550					TH	80	TH	80			CC																	
		Low		Yes	P,F	550	PT	400					TH	65			TH	60	CC															
		High		Yes	P,F	550	PT	400			TH	80	TH	80			CC																	
Pine-Oak	Natural	Low		No	N										TH	65p/50h					CC													
		High		No	N								TH	50p/50h			TH	45p/45h			CC													
		Low		Yes	N						TH	350p/200h			TH	70					CC													
		High		Yes	N								TH	50p/50h			TH	45p/45h			CC													
	Planted	Low		No	Pl pine	500									TH	65p/50h					CC													
		High		No	Pl pine	300							STS	50p/50h			STS	45p/45h			CC													
		Low		Yes	Pl pine	500					TH	350p/200h			TH	70					CC													
		High		Yes	Pl pine	300							TH	50p/50h			TH	45p/45h			CC													
Upland Hardwood	Natural	Low		No	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		No	N										CT	80					STS	50			STS	30					CC			
		Low		Yes	STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50			STS	50
		High		Yes	N								TH	70					STS	50			STS	30							CC			
Bottomland Hardwood	Natural	Low		No	N										TH	80									CC									
		High		No	N										TH	80							CC											
		Low		Yes	N								TH	65					TH	80					CC									
		High		Yes	N								TH	70					TH	80			CC											

Table B-4. Age class distribution by forest type, regeneration type, and site class for eco-section 2311 (Central Appalachian Piedmont).

			Age																										
Type	Regen	Site Class	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
Loblolly/Shortleaf	Natural	Low	0	9	29	26	29	24	27	21	13	27	26	21	17	13	11	5	4	2	1	2	0	0	0	0	0	0	0
		High	0	2	3	2	3	9	13	4	9	14	11	8	6	6	4	1	3	0	0	0	0	0	0	0	0	0	0
	Planted	Low	0	48	67	49	42	49	38	19	12	6	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		High	0	3	2	9	10	18	16	5	5	2	2	3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Pine-Oak	Natural	Low	11	42	3	181	72	3	192	4	16	211	2	11	131	8	21	81	1	3	3	0	3	0	0	1	0	0	0
		High	0	2	0	1	3	2	5	6	6	9	4	4	3	7	2	0	2	1	1	0	0	0	0	0	0	0	0
Upland Hardwood	Natural	Low	39	48	0	834	74	1	585	5	57	807	9	94	899	5	766	96	5	503	61	5	231	5	11	1	1	2	0
		High	0	113	3	5	4	7	10	7	7	108	8	11	10	13	5	2	1	6	4	0	1	0	1	0	0	0	1
Bottomland Hardwood	Natural	Low	0	4	8	103	3	10	4	8	6	11	13	14	139	9	7	9	11	3	2	1	0	2	0	1	0	0	0
		High	0	0	0	0	2	2	2	3	2	1	2	0	1	1	2	1	0	0	0	0	0	0	0	0	0	0	0

Table B-5. Non-sprouting regeneration data for loblolly-shortleaf pine plantations in eco-section 231I (Central Appalachian Piedmont). Since loblolly is planted it will not be naturally regenerated for the planation simulation.

Species	FIA_Code	FVS_Code	Sprout (1=yes)?	Trees/ac.	DBH (in)	Ht (ft)	CR (%)
eastern redcedar	68	OS	0	6.4	1.7	17	72
loblolly pine	131	LP	0	103.4	2.9	22	41
mockernut hickory	409	OH	0	4.2	1.7	22	41
pignut hickory	403	OH	0	2.7	1.7	23	51
shagbark hickory	407	OH	0	0.3	1.5	20	35
shortleaf pine	110	SP	0	0.5	4.6	34	34
Virginia pine	132	VP	0	23.0	2.4	21	36
willow oak	831	OH	0	2.5	2.5	24	38
river birch	373	OH	0	0.3	2.3	37	25

Table B-6. Non-sprouting regeneration data for natural upland hardwood stands in eco-section 231I (Central Appalachian Piedmont).

Species	FIA_Code	FVS_Code	Sprout (1=yes	Trees/ac.	DBH (in)	Ht (ft)	CR (%)
eastern hemlock	261	OS	0	0.1	1.0	12	90
eastern redcedar	68	OS	0	5.1	2.3	20	53
eastern white pine	129	WP	0	1.3	2.2	17	46
loblolly pine	131	LP	0	2.7	3.1	24	36
mockernut hickory	409	OH	0	2.3	2.4	27	37
pignut hickory	403	OH	0	4.4	2.4	26	34
shagbark hickory	407	OH	0	0.3	2.1	25	33
shortleaf pine	110	SP	0	0.2	3.9	45	28
Virginia pine	132	VP	0	3.6	2.5	22	32
willow oak	831	OH	0	0.9	2.0	24	49
river birch	373	OH	0	0.1	2.4	25	55
mountain or Fraser magnolia	655	OH	0	0.2	1.2	16	55
umbrella magnolia	658	OH	0	0.5	2.3	24	29
bitternut hickory	402	OH	0	0.5	2.4	30	22
red mulberry	682	OH	0	0.1	3.6	32	45
pitch pine	126	PP	0	0.2	3.4	21	30
American basswood	951	OH	0	0.2	3.7	34	35

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Attachment 5

Research Paper

Duncan Brack
Environment, Energy and Resources Department | February 2017

Woody Biomass for Power and Heat

Impacts on the Global Climate

CHATHAM HOUSE
The Royal Institute of International Affairs

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Executive Summary

The use of wood for electricity generation and heat in modern (non-traditional) technologies has grown rapidly in recent years. For its supporters, it represents a relatively cheap and flexible way of supplying renewable energy, with benefits to the global climate and to forest industries. To its critics, it can release more greenhouse gas emissions into the atmosphere than the fossil fuels it replaces, and threatens the maintenance of natural forests and the biodiversity that depends on them. Like the debate around transport biofuels a few years ago, this has become a highly contested subject with very few areas of consensus. This paper provides an overview of the debate around the impact of wood energy on the global climate, and aims to reach conclusions for policymakers on the appropriate way forward.

Although there are alternatives to the use of wood for biomass power and heat, including organic waste, agricultural residues and energy crops, they tend to be less energy-dense, more expensive and more difficult to collect and transport. Wood – and particularly wood pellets, now the dominant solid biomass commodity on world markets – is therefore likely to remain the biomass fuel of choice for some time.

Biomass is classified as a source of renewable energy in national policy frameworks, benefiting from financial and regulatory support on the grounds that, like other renewables, it is a carbon-neutral energy source. It is not carbon-neutral at the point of combustion, however; if biomass is burnt in the presence of oxygen, it produces carbon dioxide. The argument is increasingly made that its use can have negative impacts on the global climate. This classification as carbon-neutral derives from either or both of two assumptions. First, that biomass emissions are part of a natural cycle in which forest growth absorbs the carbon emitted by burning wood for energy. Second, that biomass emissions are accounted for in the land-use sector, and not in the energy sector, under international rules for greenhouse gas emissions.

Is biomass carbon-neutral?

The first assumption is that woody biomass emissions are part of a natural cycle in which, over time, forest growth balances the carbon emitted by burning wood for energy. In fact, since in general woody biomass is less energy dense than fossil fuels, and contains higher quantities of moisture and less hydrogen, at the point of combustion burning wood for energy usually emits more greenhouse gases per unit of energy produced than fossil fuels. The volume of emissions per unit of energy actually delivered in real-world situations will also depend on the efficiency of the technology in which the fuel is burnt; dedicated biomass plants tend to have lower efficiencies than fossil fuel plants depending on the age and size of the unit. The impact on the climate will also depend on the supply-chain emissions from harvesting, collecting, processing and transport. Estimates of these factors vary widely but they can be very significant, particularly where methane emissions from wood storage are taken into account. Overall, while some instances of biomass energy use may result in lower life-cycle emissions than fossil fuels, in most circumstances, comparing technologies of similar ages, the use of woody biomass for energy will release higher levels of emissions than coal and considerably higher levels than gas.

The impacts on the climate will also vary, however, with the type of woody biomass used, with what would have happened to it if it had not been burnt for energy and with what happens to the forest from which it was sourced.

Biomass energy feedstocks

The harvesting of whole trees for energy will in almost all circumstances increase net carbon emissions very substantially compared to using fossil fuels. This is because of the loss of future carbon sequestration from the growing trees – particularly from mature trees in old-growth forests, whose rate of carbon absorption can be very high – and of the loss of soil carbon consequent upon the disturbance.

The use of sawmill residues for energy has lower impacts because it involves no additional harvesting; it is waste from other operations of the wood industry. The impact will be most positive for the climate if they are burnt on-site for energy without any associated transport or processing emissions. However, mill residues can also be used for wood products such as particleboard; if diverted instead to energy, this will raise carbon concentrations in the atmosphere. The current high levels of use of mill residues mean that this source is unlikely to provide much additional feedstock for the biomass energy industry in the future (or, if it does, it will be at the expense of other wood-based industries). Black liquor, a waste from the pulp and paper industry, can also be burnt on-site for energy and has no other use; it is in many ways the ideal feedstock for biomass energy.

The use of forest residues for energy should also imply no additional harvesting, so its impacts on net carbon emissions can be low (though whole trees can sometimes be misclassified as residues). This depends mainly on the rate at which the residues would decay and release carbon if left in the forest, which can vary substantially. If slow-decaying residues are burnt, the impact would be an increase in net carbon emissions potentially for decades. In addition, removing residues from the forest can adversely affect soil carbon and nutrient levels as well as tree growth rates.

Many of the models used to predict the impacts of biomass use assume that mill and forest residues are the main feedstock used for energy, and biomass pellet and energy companies tend to claim the same, though they often group 'low-grade wood' with 'forest residues', although their impact on the climate is not the same. Evidence suggests, however, that various types of roundwood are generally the main source of feedstock for large industrial pellet facilities. Forest residues are often unsuitable for use because of their high ash, dirt and alkali salt content.

Biomass and the forest carbon cycle

It is often argued that biomass emissions should be considered to be zero at the point of combustion because carbon has been absorbed during the growth of the trees, either because the timber is harvested from a sustainably managed forest, or because forest area as a whole is increasing (at least in Europe and North America). The methodology specified in the 2009 EU Renewable Energy Directive and many national policy frameworks for calculating emissions from biomass only considers supply-chain emissions, counting combustion emissions as zero.

These arguments are not credible. They ignore what happens to the wood after it is harvested (emissions will be different if the wood is burnt or made into products) and the carbon sequestration forgone from harvesting the trees that if left unharvested would have continued to grow and absorb carbon. The evidence suggests that this is true even for mature trees, which absorb carbon at a faster

rate than young trees. Furthermore, even if the forest is replanted, soil carbon losses during harvesting may delay a forest's return to its status as a carbon sink for 10–20 years.

Another argument for a positive impact of burning woody biomass is if the forest area expands as a direct result of harvesting wood for energy, and if the additional growth exceeds the emissions from combustion of biomass. Various models have predicted that this could be the case, but it is not yet clear that this phenomenon is actually being observed. For example, the timberland area in the southeast of the US (where most US wood pellet mills supplying the EU are found) does not appear to be increasing significantly. In any case, the models that predict this often assume that old-growth forests are replaced by fast-growing plantations, which in itself leads to higher carbon emissions and negative impacts on biodiversity.

The carbon payback approach argues that, while they are higher than when using fossil fuels, carbon emissions from burning woody biomass can be absorbed by forest regrowth. The time this takes – the carbon payback period before which carbon emissions return to the level they would have been at if fossil fuels had been used – is of crucial importance. There are problems with this approach, but it highlights the range of factors that affect the impact of biomass and focuses attention on the very long payback periods of some feedstocks, particularly whole trees.

The many attempts that have been made to estimate carbon payback periods suggest that these vary substantially, from less than 20 years to many decades and in some cases even centuries. As would be expected, the most positive outcomes for the climate, with very low payback periods, derive from the use of mill residues (unless they are diverted from use for wood products). If forest residues that would otherwise have been left to rot in the forest are used, the impact is complex, as their removal may cause significant negative impacts on levels of soil carbon and on rates of tree growth. The most negative impacts involve increasing harvest volumes or frequencies in already managed forests, converting natural forests into plantations or displacing wood from other uses.

Some have argued that the length of the carbon payback period does not matter as long as all emissions are eventually absorbed. This ignores the potential impact in the short term on climate tipping points (a concept for which there is some evidence) and on the world's ability to meet the target set in the 2015 Paris Agreement to limit temperature increase to 1.5°C above pre-industrial levels, which requires greenhouse gas emissions to peak in the near term. This suggests that only biomass energy with the shortest carbon payback periods should be eligible for financial and regulatory support.

BECCS

There is growing interest in the combination of bioenergy with carbon capture and storage (BECCS) with the aim of providing energy supply with net negative emissions. The latest assessment report of the Intergovernmental Panel on Climate Change (IPCC) relies heavily on bioenergy for heat and power, and specifically on BECCS, in most of its scenarios of future mitigation options. However, all of the studies that the IPCC surveyed assumed that the biomass was zero-carbon at the point of combustion, which, as discussed above, is not a valid assumption. In addition, the slow rate of deployment of carbon capture and storage technology, and the extremely large areas of land that would be required to supply the woody biomass feedstock needed in the BECCS scenarios render its future development at scale highly unlikely. The reliance on BECCS of so many of the climate mitigation scenarios reviewed by the IPCC is of major concern, potentially distracting attention

from other mitigation options and encouraging decision makers to lock themselves into high-carbon options in the short term on the assumption that the emissions thus generated can be compensated for in the long term.

Recommendations

- In assessing the climate impact of the use of woody biomass for energy, changes in the forest carbon stock must be fully accounted for. It is not valid to claim that because trees absorb carbon as they grow, the emissions from burning them can be ignored.
- Along with changes in forest carbon stock, a full analysis of the impact on the climate of using woody biomass for energy needs to take into account the emissions from combustion (which are generally higher than those for fossil fuels) and the supply-chain emissions from harvesting, collection, processing and transport. There is still some uncertainty over some of these factors and further research would be helpful.
- The provision of financial or regulatory support to biomass energy on the grounds of its contribution to mitigating climate change should be limited only to those feedstocks that reduce carbon emissions over the short term.
- In practice, this means that support should be restricted to sawmill residues, together with post-consumer waste. Burning slower-decaying forest residues or whole trees means that carbon emissions stay higher for decades than if fossil fuels had been used.

Accounting for biomass carbon emissions

The second assumption that leads to the perception that biomass energy is zero-carbon at the point of combustion derives from the international greenhouse gas reporting and accounting frameworks established under the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. In order to avoid double-counting emissions from biomass energy within the energy sector (when the biomass is burned) and the land-use sector (when the biomass is harvested), the rules provide that emissions should be reported within the land-use sector only.

While this approach makes sense for *reporting*, it has resulted in significant gaps in the context of *accounting* – measuring emissions levels against countries' targets under the Kyoto Protocol (or, potentially, the Paris Agreement), largely deriving from the different forest-management reference levels that parties have been permitted to adopt. The problem of 'missing', or unaccounted-for, emissions arises when a country using biomass for energy:

- Imports it from a country outside the accounting framework – such as the US, Canada or Russia, all significant exporters of woody biomass that do not account for greenhouse gas emissions under the second commitment period of the Kyoto Protocol;
- Accounts for its biomass emissions using a historical forest-management reference level that includes higher levels of biomass-related emissions than in the present; or
- Accounts for its biomass-related emissions using a business-as-usual forest-management reference level that includes, explicitly or implicitly, anticipated emissions from biomass energy (since the associated emissions built in to the projection will not count against its national target).

This risks creating perverse policy outcomes. Where a tonne of emissions from burning biomass for energy does not count against a country's emissions target but a tonne of emissions from fossil fuel sources does, there will be an incentive to use biomass energy rather than fossil fuels in order to reduce the country's greenhouse gas emissions – even where this reduction is not 'real' in the sense that it is not accounted for by either the user or the source country.

The quantity of emissions missing from the international greenhouse gas accounting framework is impossible to calculate precisely. Forest-management reference level submissions do not contain sufficient information on the quantity of woody biomass projected to be used, the origins of that biomass (additional domestic forest harvests, increased use of domestic forestry residues or higher imports) and the resulting emissions. Nevertheless, the quantity of emissions is likely to be significant, as demonstrated in several country case studies.

In 2014, countries listed in Annex I to the UNFCCC in aggregate emitted 985 million tonnes of carbon dioxide ($MtCO_2$) from biomass combustion, including an estimated 781 $MtCO_2$ from solid biomass. The latter figure is equivalent to 5.6 per cent of aggregate, economy-wide carbon dioxide emissions from Annex I countries in 2014, and 6 per cent of their total energy emissions. The US accounts for almost 28 per cent of total Annex I solid biomass carbon emissions, while Germany, Japan and France account for a further 26 per cent. Neither the US nor Japan account for emissions from their land-use sectors under the Kyoto Protocol, while Germany accounts against a business-as-usual projection that does not explicitly include bioenergy policies, and France uses a business-as-usual projection that includes bioenergy demand from policies up to, but not including, the EU Renewable Energy Directive. Woody biomass emissions from all these countries, therefore, have the potential to go unaccounted for.

Recommendations

Four steps could be taken within the existing framework to reduce the potential for missing emissions:

- All parties to the Kyoto Protocol and the Paris Agreement should include the land-use sector in their national accounting.
- Forest-management reference levels should contain detailed information on projected emissions from using biomass for energy, the origins of that biomass (additional domestic forest harvests or increased use of domestic forestry residues) and the resulting emissions.
- Countries that import biomass for energy should be required to report on whether and how the country of origin accounts for biomass-based emissions. Emissions associated with biomass imported from a country that does not account for such emissions, or from one that has built biomass energy demand into its accounting baseline, should be fully accounted for by the importing country.
- Countries using domestic biomass for energy should reconcile their energy and land-use sector accounting approaches in order to put emissions from each sector on a par with each other, if possible through using the same benchmarks – either a historical reference year/period or a business-as-usual scenario – to avoid emissions leakage between the sectors. This should be uniform across all countries.

If the land-use accounting rules are not reformed as suggested above, a more radical option would be to account for carbon dioxide emissions from biomass burned for energy within the energy sector, with additional rules to avoid double-counting in the land-use sector.

Sustainability criteria

One means of avoiding, or at least ameliorating, the impacts on the climate of the use of woody biomass for energy is to apply preconditions that biomass installations are required to meet before they are eligible for the regulatory and financial support afforded to renewable energy sources. The European Commission published proposals for sustainability criteria for solid biomass in late 2016. Many EU member states already apply some criteria; the most detailed have been developed in Belgium, Denmark, the Netherlands and the UK.

In general these have two components: requirements for minimum levels of greenhouse gas savings compared to fossil fuels, and requirements (often called 'land criteria') relating to the legality and sustainability of forest management, usually taken from national timber procurement policies. Sometimes other criteria, such as restrictions on types of feedstock or on minimum plant energy efficiency levels, are also included. However, none of these systems includes changes in levels of forest carbon stock in their calculation of greenhouse gas savings (apart from direct land-use change), though the Dutch criteria contain a requirement that the forest is managed with the aim of retaining or increasing carbon stocks in the medium or long term, and the EU proposed criteria include a requirement for the country from which the forest biomass is sourced to be a party to the Paris Agreement, which accounts for changes in carbon stock associated with biomass harvests.

Several voluntary certification schemes have developed with the aim of including climate impacts alongside other criteria, such as sustainable forest management. The main one is the Sustainable Biomass Partnership (SBP), established in 2013 by seven major European utility companies. Its standard includes the need to define the supply base of the biomass, to ensure feedstock can be traced back to its source area, and a requirement that 'regional carbon stocks are maintained or increased over the medium to long term'. The standard includes a calculation of the energy and carbon balance of the biomass used for energy, but this does not include changes in forest carbon stock. Verification involves a regional approach that uses a desk-based assessment against the criteria leading to a risk rating for each indicator. Where risks are identified, appropriate mitigation measures must be defined, implemented and monitored.

These schemes' failures to account, comprehensively or at all, for changes in forest carbon stock mean they cannot be considered as satisfactory. Effectively, their criteria permit the provision of financial and regulatory support to policy options that could increase carbon emissions in the short and medium term, and possibly in the long term too. The references to forest carbon stock in the Dutch and SBP's criteria are too vague. Forest carbon stock levels may stay the same or increase for reasons entirely unconnected with use for energy. The important issue is what levels they would have reached in the absence of biomass energy use. Similarly, the requirement in the proposed EU criteria for land-use sector accounting in the country of origin to take account of changes in forest carbon stock is a step in the right direction. It is still subject to the flaws identified earlier, however, and cannot take account of the full climate impact of the use of forest residues, which may be significantly underestimated in current models, given the potential effects on soil carbon levels and tree growth rates.

To date, no national biomass sustainability standards have been developed outside the EU, though the US state of Massachusetts restricts eligibility for subsidies based on net carbon accounting over a 20-year timeframe, and includes sustainability provisions such as the requirement that harvests leave sufficient woody material on the forest floor to replenish soil nutrients and protect wildlife. In addition, biomass plants must demonstrate emissions reductions over time on the basis of life-cycle emissions analyses, including a carbon-debt emissions factor, and must satisfy a minimum efficiency level.

Recommendations

- Robust sustainability criteria must deal with the impact on greenhouse gas emissions and the legality and sustainability of forest management.
- One option would be for the greenhouse gas element to be underpinned by a comprehensive life-cycle analysis for each type of feedstock, including changes in the forest carbon stock alongside supply-chain emissions. However, this is a complex calculation depending partly on the counterfactual (what would have happened to the wood, and the forest from which it was sourced, if it had not been used for energy?) and difficult to implement in real life.
- A more practical approach is to restrict eligibility for support to those feedstocks that are most likely to reduce net carbon emissions (or have low carbon payback periods): primarily mill residues, together with post-consumer waste. An additional element could be a requirement for a minimum level of efficiency of the unit in which the biomass is burnt.
- Policies should also ensure that subsidies do not encourage the biomass industry to divert raw material (such as mill residues) away from alternative uses (such as fibreboard), which have far lower impacts on carbon emissions.
- Alongside these emissions criteria, land criteria for legal and sustainable sourcing should be used to protect the way in which the forests are managed. Risk-based assessments of areas lacking coverage of forest certification schemes should supplement desk-based assessments with on-the-ground inspections.

Introduction

The use of wood for electricity generation and heat in modern (non-traditional) technologies has grown rapidly in recent years. For its supporters, it represents a relatively cheap and flexible way of supplying renewable energy, with benefits to the global climate and to forest industries. To its critics, it can release more greenhouse gas emissions into the atmosphere than the fossil fuels it replaces, and threatens the maintenance of natural forests and the biodiversity that depends on them. Just like the debate around transport biofuels a few years ago, this has become a highly contested subject with very few areas of consensus.

This paper aims to provide an overview of the debate around the impact of wood energy on the global climate, and to reach conclusions for policymakers on the appropriate way forward.

Global demand and supply

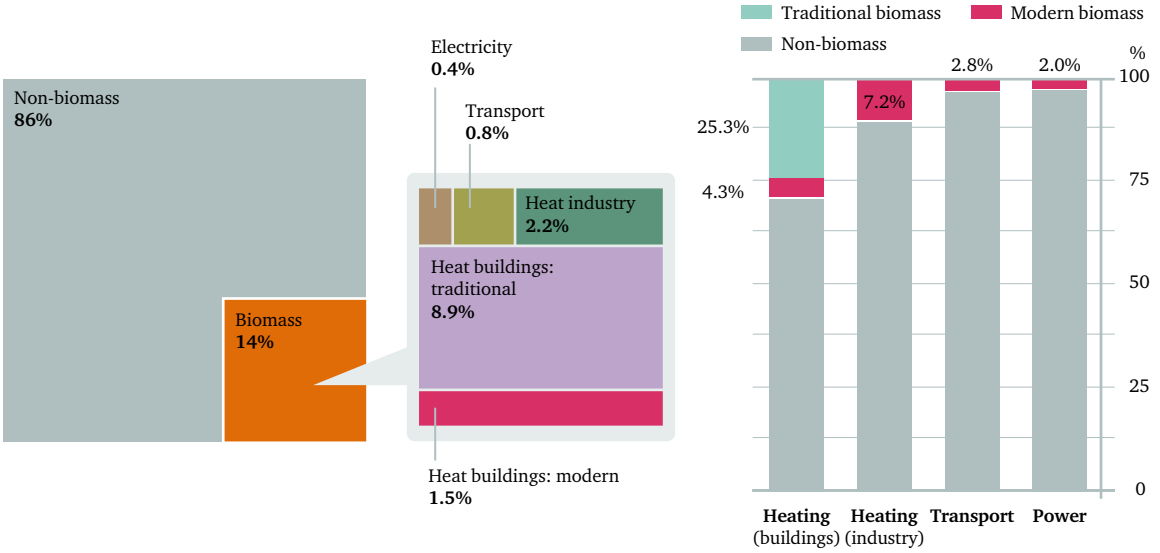
In energy policy terms, wood is one form of solid biomass, with other forms being agricultural crops and residues, herbaceous and energy crops, and organic wastes such as food waste or manure. Biomass-based energy is the oldest source of consumer energy known to humans, and is still the largest source of renewable energy worldwide, accounting for an estimated 8.9 per cent of world total primary energy supply in 2014.[1] Most of this is consumed in rural areas of non-industrialized or less industrialized parts of the world for cooking and heating, usually on open fires or in simple cookstoves. Together with the use of wood charcoal, these are categorized as 'traditional' uses and are not covered in this paper or its companion papers.

The focus here is on the combustion of woody biomass to produce electricity or heat, or both, through modern, non-traditional technologies: power stations, combined heat and power facilities, industrial processes such as pulp and paper mills, modern biomass burners, and so on. Biomass can also be co-fired with coal; coal plants do not need to be modified up to a mix of about 5 per cent biomass, making this the cheapest way of using biomass for power.

Taken together with bioliquids (which are mainly used for transport fuel) and biogas, these forms of biomass are the largest source of modern renewable energy used worldwide, accounting for an estimated 5.1 per cent of total final energy consumption in 2014. Heating for industry and buildings accounts for the bulk of this, while combustion for electricity is comparatively small, though it has grown rapidly in recent years (see Figure 1).

[1] United Nations Environment Programme (2016), *Renewables 2016: Global Status Report*, Nairobi: United Nations Environment Programme, p. 28.

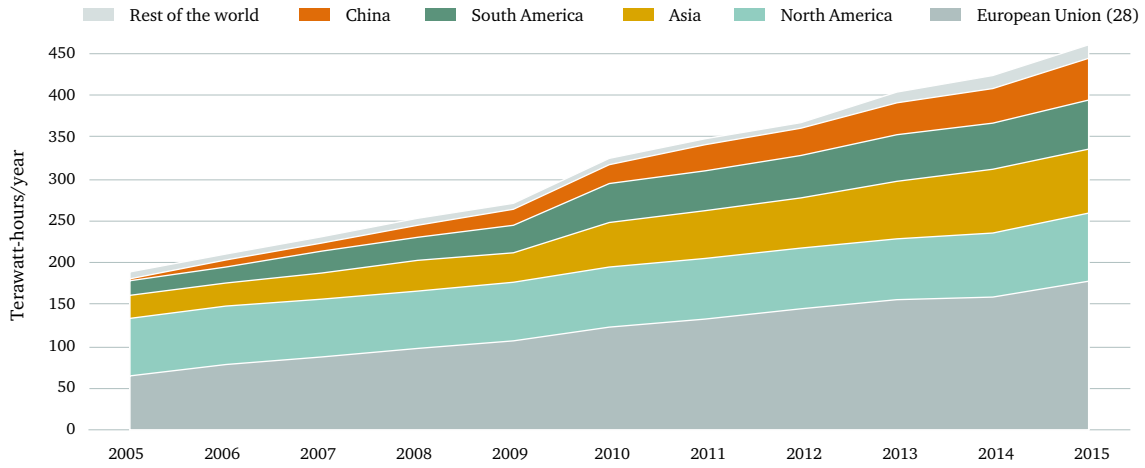
Figure 1: Shares of traditional and modern biomass (solid, liquid and gaseous) in total final energy consumption and in final energy consumption by end-use sector, 2014



Source: United Nations Environment Programme (2016), *Renewables 2016: Global Status Report*, Nairobi: United Nations Environment Programme, p. 43.

The growth of biomass energy has the potential to continue as countries increasingly adopt support policies for these uses of biomass, primarily in response to climate and energy security concerns. In the EU – the largest global consumer of modern biomass energy – a major driver has been the 2020 targets set for member states under the 2009 Renewable Energy Directive. In 2012, of the over $7 billion invested in biomass-based power worldwide, Europe was the leader, accounting for about one-third.[2] While the EU has the largest share of biomass-fired electricity generation, the US, China, Japan, India and Brazil are all also significant consumers (see Figure 2).

Figure 2: Bio-power global generation, by country/region, 2005–15



Source: United Nations Environment Programme (2016), *Renewables 2016: Global Status Report*, Nairobi: United Nations Environment Programme, p. 45.

[2] Roberts, D. G. (2013), 'International Wood Fibre Markets (and Emerging Shocks)', presentation at Megaflorestais conference, Bali, October 2013.

Most analyses assuming expansion in renewable energy envisage significant growth in the use of biomass, at least to 2030 and often beyond. In 2012, for example, the International Energy Agency (IEA) estimated that, as long as appropriate policies were in place by 2050, bioenergy (wood and other forms of biomass) could provide 3,100 terawatt hours (TWh) of electricity (7.5 per cent of total world electricity generation, an eight-fold increase from 2011), 22 exajoules (EJ) of final heat consumption in industry (15 per cent of the total, a tripling of the total) and 24 EJ in the buildings sector (20 per cent of the total, though this represented a fall from 35 EJ in 2009 as inefficient traditional forms of heating were gradually replaced).[3]

These estimates may be revised downwards, however, particularly for electricity generation, as the cost of other forms of renewable energy – mainly solar photovoltaic (PV) and wind – have fallen significantly in recent years and seem likely to reach grid parity with fossil fuel-sourced electricity very soon without subsidy. However, biomass energy has the advantage over solar and wind of being 'dispatchable'; i.e. the electricity it generates can be dispatched at the request of power grid operators or of the plant owner. Biomass plants can be turned on or off, or can adjust their power output according to need, whereas solar, wind and hydroelectric power are present or not depending on the conditions (apart from pumped-storage hydroelectricity).[4]

In addition, there is growing interest in the combination of bioenergy and carbon capture and storage technology (BECCS) with the aim of providing energy supply with net negative emissions. The latest assessment report of the Intergovernmental Panel on Climate Change (IPCC) relies heavily on bioenergy for heat and power, and specifically on BECCS, in most of its scenarios of future mitigation options (see Chapter 1).[5] Despite the falling price and growing share of other forms of renewable energy, biomass accordingly retains some potential for future growth.

Wood for power and heat

There are alternatives to the use of wood in biomass power and heat, including organic wastes, agricultural residues such as sugarcane bagasse or palm kernels, and energy crops such as miscanthus (elephant grass) or switchgrass. Agricultural wastes and residues are, or are planned to be, important sources of biomass energy in China, India and Brazil, and energy crops may become more significant in the EU, though there is considerable uncertainty over the likely availability of land for their cultivation, among other factors.[6] However, all these forms of biomass tend to be less energy dense and more expensive to grow, collect and transport than wood. Wood is therefore likely to remain overwhelmingly the biomass fuel of choice for electricity generation and heat, at least in the short and medium term, as it is now in Europe, North America and Japan.

Wood in various forms can be used for electricity generation and heat. Primary end-products that are used for this purpose include:

- **Fuelwood (or firewood):** Simple logs, branches, twigs and so on, produced from logging, or thinnings and coppicings from managed forests. This is the simplest form of wood for fuel and

[3] International Energy Agency (IEA) (2012), *Technology Roadmap: Bioenergy for Heat and Power*, Paris: IEA, http://www.iea.org/publications/freepublications/publication/2012_Bioenergy_Roadmap_2nd_Edition_WEB.pdf (accessed 28 Dec. 2016).
[4] These issues will be discussed at more length in the companion paper, *Woody Biomass for Power and Heat: Global Patterns of Demand and Supply.*
[5] Intergovernmental Panel on Climate Change IPCC (2014), *Climate Change 2014: Mitigation of Climate Change,* Cambridge: Cambridge University Press, http://www.ipcc.ch/pdf/assessment-report/ar5/wg3/ipcc_wg3_ar5_full.pdf (accessed 28 Dec. 2016).
[6] See, for example, Allen, B. et al. (2014), *Space for energy crops – assessing the potential contribution to Europe's energy future,* London: Institute for European Environmental Policy, http://www.birdlife.org/sites/default/files/attachments/IEEP_2014_Space_for_Energy_Crops_0.pdf (accessed 30 Dec. 2016).

requires no processing, but it is bulky and contains high levels of moisture. It can therefore be relatively difficult and costly to collect and transport.

- **Wood chips:** Medium-sized solid material (typically 30–60 mm in size) made by cutting, or chipping, larger pieces of wood. Wood chips are easier than fuelwood to transport and store but can contain just as much moisture. Globally, most high-quality chips are used for composite-board products such as oriented strandboard or the production of pulp and paper; lower-quality wood chips may be used for energy, particularly where the transport distances to the installation are relatively low.
- **Wood pellets:** These are produced by compressing wood material and extruding it through a die into cylinders (normally 6–12 mm in diameter and 10–30 mm in length). This process, together with the necessary drying of the wood, requires energy input. Compared to wood chips, pellets are more dense and have a lower moisture content, and are therefore better suited to transport and storage. They are now the favoured form of wood for biomass power generation, particularly where transport distances are great. Pellets can be made from any organic material, including agricultural wastes, sawdust or other wastes from sawmilling and wood product manufacturing, but many power stations, particularly those co-firing wood pellets with coal, can only use clean wood mainly sourced from whole trees (see Chapter 1).
- **Wastes and residues:** Bark, shavings, sawdust, trim ends, offcuts and so on can be burned for energy on-site in sawmills where they are produced or made into pellets. Residues from forest operations – stumps, tops, small branches and pieces too short or defective to be used for other purposes – can also be made into chips or pellets, but, as noted earlier, their quality is sometimes too low to be used in power stations.
- **Black liquor:** A waste product from pulp and paper mills, this is generally burnt in recovery boilers on-site to generate energy for the mill and often also for export to the local electricity grid. Although it is a liquid, black liquor is generally classified as solid biomass, and forms a substantial share of the wood-based fuel consumed in some EU member states and the US (see Chapter 1).

Several new technologies for using wood for energy are under development. So-called 'torrefied pellets', 'black pellets' or 'biocoal' are normal ('white') pellets heated in the absence of oxygen to further reduce moisture and sugar content. Compared to white pellets, they have a higher energy density (though also require more energy to produce) and are water-resistant and more robust in handling, and they can be more easily burned in coal stations.[7] Wood (and other organic material) can also be gasified and the gas produced then used directly for electricity generation or fed into gas networks for heating or adapted for transport; though this technology has not been extensively commercialized so far.

[7] Several slightly different processes can be used to produce torrefied or black pellets, including thermal roasting and steam explosion. While technically these are not the same, the end products are similar and the terms 'black pellet' or, less commonly, 'biocoal', are often used to describe them all.

About this paper

In national policy frameworks, biomass is always classified as a source of renewable energy, alongside other technologies such as solar PV, wind or tidal power. It benefits from the same kind of financial and regulatory support as those technologies on the grounds that, like other renewables, it is a carbon-neutral energy source. However, at the point of combustion, biomass is not carbon-neutral – if wood or other organic material is burnt in the presence of oxygen, it produces carbon dioxide – and the argument is increasingly being made that its use can have negative impacts on the global climate.

This classification of biomass as carbon-neutral derives from either one of two assumptions. The first is that biomass emissions are part of a natural cycle in which, over time, forest growth balances the carbon emitted by burning wood for energy. Chapter 1 examines this assumption.

The second assumption derives from IPCC reporting rules intended to avoid the double-counting of carbon emissions, which determine that emissions from wood energy are accounted for in the land-use sector and not in the energy sector. In effect, emissions are assumed to occur at the point of harvest, not at the point of burning, and thus biomass energy is carbon-neutral from the energy-sector perspective. Chapter 2 examines the framework for reporting and accounting of biomass emissions.

Governments, particularly those in the EU, have not been immune to the growing concerns over the impacts of the use of biomass for power and heat explored in this paper, and some have introduced or are planning to introduce sustainability criteria designed to minimize the environmental impact of biomass: biomass feedstocks must meet these requirements if they are to receive financial and regulatory support. Some private schemes are also being developed. Chapter 3 examines this development and considers the likely impact of the criteria currently in use or development.

This is the first of four papers to be published by Chatham House on this topic. Two more – *Woody Biomass for Power and Heat: Global Patterns of Demand and Supply* and *Woody Biomass for Power and Heat: Demand and Supply in Selected EU Member States* will review the recent and anticipated growth of demand for wood for electricity generation and heat in modern technologies on a global scale and in specific countries, and assess the likely sources of supply, in recent years and in the future. The fourth paper, *Woody Biomass for Power and Heat: Impacts on the Local Environment and Forest Users*, will consider the impacts of the use of woody biomass for energy on forest ecosystems and on other forest users.

1. Is Biomass Carbon-neutral?

This chapter reviews the argument that biomass emissions are part of a natural cycle in which forest growth balances the carbon emitted by burning wood for energy. The following issues are discussed:

- The level of greenhouse gases emitted by woody biomass when burnt, compared to those of the fossil fuels it potentially replaces.
- The types of woody biomass used for energy and their potential impact on carbon emissions.
- The relationship between the emissions from burning woody biomass and forest growth or regrowth, and the time forest growth may take to absorb the emissions from burning woody biomass (the 'carbon payback period').
- The debate around bioenergy with carbon capture and storage.

Most of the studies carried out on these topics relate to the sourcing of woody biomass from the US, generally for export and use in the EU. This is a relatively small proportion of total global use of woody biomass for energy, even in modern technologies. Across the UN Economic Commission for Europe region (Europe, North America, and north, west and central Asia), forest-based industries form the largest end-use sector, consuming over 40 per cent of wood energy.[8] However, the use of woody biomass for heat and power is growing more quickly, particularly in the EU, and imports from outside the EU, chiefly from the US and Canada, have risen sharply in recent years. This is likely to continue. It is estimated that, if it is to achieve its aim of providing 27 per cent of its energy consumption from renewable sources by 2030, the amount of biomass the EU will need is the equivalent to the total EU wood harvest for all purposes in 2015.[9] While studies based on the US may not always be applicable to the sourcing of woody biomass in other regions, they focus attention on the country that has experienced most rapid recent changes in this respect and many of the conclusions they reach are applicable more broadly.

Greenhouse gas emissions from burning woody biomass

Since in general woody biomass is less energy dense than fossil fuels, and contains higher quantities of moisture and less hydrogen, at the point of combustion burning wood for energy usually emits more greenhouse gases per unit of energy produced than is the case with fossil fuels.[10] Table 1 presents the emission factors agreed by the IPCC in 2006 and widely used, for example, in emissions calculations under the EU Emissions Trading Scheme and for some national inventory reports under the UN Framework Convention on Climate Change.

[8] Griffiths, J. (2016), *Scoping Dialogue on Sustainable Woody Biomass for Energy*, p. 8, New Haven, CT: The Forests Dialogue, http://theforestsdialogue.org/sites/default/files/files/TFD%20Bankground%20Paper%20Scoping%20dialogue%20Sustainable%20Woody%20Biomass%20DRAFT%2020%2022%20June%202016(1).pdf (accessed 30 Dec. 2016).
[9] Strange Olesen, A. et al. (2015), *Environmental Implications of Increased Reliance of the EU on Biomass from the South East US,* p. 8, Brussels: European Commission, http://www.aebiom.org/wp-content/uploads/2016/08/DG-ENVI-study-imports-from-US-Final-report-July-2016.pdf (accessed 30 Dec. 2016).
[10] As noted in, for example, Agostini, A., Giuntoli, J. and Boulamanti, A. (2013), *Carbon accounting of forest bioenergy: Conclusions and recommendations from a critical literature review,* p.16, European Commission Joint Research Centre, http://publications.jrc.ec.europa.eu/repository/bitstream/JRC70663/eur25354en_online.pdf (accessed 30 Dec. 2016); and IEA Bioenergy Task 38 on Climate Change Effects of Biomass and Bioenergy Systems (2013), 'Description of IEA Task 38', http://www.task38.org/publications/task38_description_2013.pdf (accessed 30 Dec. 2016).

Table 1: Greenhouse gas emissions of wood, coal and natural gas, net calorific basis

	Emissions (kg CO_2/TJ) (1 TJ = 278 MWh)				
Source	Wood	Anthracite	Bituminous	Lignite	Natural gas
Carbon dioxide	112,000 (95,000–132,000)	98,300 (94,600–101,000)	94,600 (89,500–99,700)	101,000 (90,900–115,000)	56,100 (54,300–58,300)
Methane	30 (10–100)	1 (0.3–3)	1 (0.3–3)	1 (0.3–3)	1 (0.3–3)
Nitrous oxide	4 (1.5–15)	1.5 (0.5–5)	1.5 (0.5–5)	1.5 (0.5–5)	0.1 (0.03–0.3)

Source: Intergovernmental Panel on Climate Change (2006), *Guidelines for National Greenhouse Gas Inventories*, Vol. 2 (Energy), Table 2.2, pp. 2.16–2.17.

The emission levels from wood are compared with emissions from natural gas and three different types of coal (anthracite, bituminous coal and lignite). The table includes ranges of factors together with the central default values agreed by the IPCC. As can be seen, wood has a wider range of carbon dioxide emissions than all of the fossil fuels. Nevertheless, while some types of wood may have lower levels of carbon emissions than some types of coal, in general wood is more carbon intensive than coal and significantly more so than natural gas, as well as having higher levels of emissions of methane and nitrous oxide.

These figures are calorific values, i.e. the energy released from complete combustion of the fuel in the presence of oxygen. The energy actually delivered in real-world situations will differ from this depending primarily on the efficiency of conversion to 'useful' energy – i.e. thermal energy and electricity. Efficiency values vary substantially depending on the plant's size, design, age and type of fuel used. The European Commission's Joint Research Centre has reported average net thermal efficiencies of coal-burning plants of 40–45 per cent and average electric efficiencies of dedicated biomass plants of 20–30 per cent.[11] More recent figures for biomass plants in the EU indicate electric efficiencies of 24–32 per cent.[12] Very large modern plants such as the Drax power station in the UK, which has converted three of its six coal-fired units to biomass, may achieve electric efficiencies of around 38 per cent, though this depends on burning wood pellets rather than green chips.

Nevertheless, even in the case of Drax, carbon emissions per unit of energy are higher for woody biomass than for coal. Table 2 shows the figures for fuel use, electricity generation and carbon dioxide emissions reported by Drax for 2013. As can be seen, the carbon dioxide intensities of the fuels are 856 kg CO_2/MWh (coal) and 965 kg CO_2/MWh (biomass), i.e. a level of emissions from biomass about 13 per cent higher than from coal.

Table 2: Fuel used, electricity generated and carbon dioxide emissions, Drax, 2013

	Weight burnt (tonnes)	Electricity generated (TWh)	CO_2 emissions (tonnes)	CO_2 intensity (kg/MWh)
Coal and petcoke	9,301,000	23.4	20,089,607	856
Biomass	1,596,000	2.9	2,799,391	965

Source: Drax, *Annual review of Environmental Performance 2013*, pp. 3, 4, 8.

[11] European Commission Joint Research Centre (2006), *Integrated Pollution Prevention and Control Reference Document on Best Available Techniques for Large Combustion Plants*, http://eippcb.jrc.ec.europa.eu/reference/BREF/lcp_bref_0706.pdf (accessed 30 Dec. 2016).
[12] Biomass Availability and Sustainability Information System (BASIS) (2015), *Report on conversion efficiency of biomass*, Version 2. http://www.basisbioenergy.eu/fileadmin/BASIS/D3.5_Report_on_conversion_efficiency_of_biomass.pdf (accessed 30 Dec. 2016).

Similarly, data provided by the US Environmental Protection Agency show that power plants burning wood tend to have higher emissions per megawatt-hour than plants burning gas or coal. To take a particular example, the Schiller power station in New Hampshire has coal boilers and a wood boiler; emissions from the wood boiler are 1,444 kg CO_2/MWh, compared to 1,243 kg CO_2/MWh for the coal boilers.[13] These solid fuel boilers are old and inefficient; new combined cycle gas boilers in the database have emission rates that are less than one third the emissions of the Schiller biomass boiler.

For biomass and fossil fuels, efficiency levels for combined heat and power (CHP), or cogeneration, plants, can be much higher – 80 per cent or more – as a much higher proportion of the heat produced during combustion is trapped and used. For example, DONG Energy's Avedøre CHP plant near Copenhagen, which is converting from coal and gas to biomass (wood pellets and straw), is claimed to be one of the most efficient in the world, achieving fuel efficiencies up to 89 per cent.[14]

In addition to the emissions produced at the point of combustion, the production and processing of the biomass gives rise to additional greenhouse gas emissions, from the energy consumed in harvesting the forest or collecting the wood, to processing it (e.g. into pellets), and transporting it. Calculations of these supply-chain emissions vary substantially.[15] A 2014 study estimated the emissions from supplying wood pellets from the southeastern US to power plants in the Netherlands, from truck, train and oceanic transport and from the process of pelletizing, as equivalent to 322 kg CO_2 per tonne of pellets. Assuming 499 kg of pellets is burnt to generate 1 MWh of electricity, this gives additional emissions of 162 kg CO_2/MWh – equivalent to about one-sixth of the emissions released during combustion (using the Drax figures above).[16]

In contrast, a 2016 study used the figure of 34.4 kg CO_2 per tonne of pellets burnt, one-tenth of that of the 2014 study.[17] The figures will vary with the particular scenario – e.g. with the distance between the forest and pellet plant, and between the plant and the power station, as well as with the amount and type of energy used in the plant – but this degree of variation seems excessive. A 2015 article calculated base-case figures of 132–140 kg carbon dioxide equivalent (CO_2-eq)/MWh but then also considered the impact of methane emissions from wood chips and sawdust during storage, either at the pellet mill or the power station. It found this raised the associated emissions to 317 kg CO_2- eq/MWh after storage for one month and 862 kg CO_2-eq/MWh after four months – higher by itself (even ignoring emissions from combustion) than emissions from coal (estimated in this study as 752 kg CO_2-eq/MWh).[18]

Given the considerable uncertainties associated with all these figures, further research would be valuable. This is particularly true for the contribution of methane emissions, which is a factor not usually included in calculations but which can have a major impact. The studies reviewed in the 2015

[13] Partnership for Policy Integrity (2012), uploaded data: 'EPA's non-cogen egrid data for 2012', http://www.pfpi.net/epas-non-cogen-egrid-data-for-2012 (accessed 20 Feb. 2017).
[14] DONG Energy (undated), 'Avedøre Power Station', http://www.dongenergy.com/en/our-business/bioenergy-thermal-power/where-we-operate (accessed 30 Dec. 2016).
[15] As noted in Wang, W. et al. (2015), 'Carbon savings with transatlantic trade in pellets: accounting for market-driven effects', pp. 4–5, *Environmental Research Letters,* 10, doi:10.1088/1748-9326/10/11/114019 (accessed 30 Dec. 2016).
[16] Jonker J. G. G., Junginger, M. and Faaij, A. (2014), 'Carbon payback period and carbon offset parity point of wood pellet production in the South-eastern United States', p. 375, *GCB Bioenergy,* 6:4, DOI: 10.1111/gcbb.12056 (accessed 30 Dec. 2016).
[17] Galik, C. S. and Abt, R. C. (2016), 'Sustainability guidelines and forest market response: an assessment of European Union pellet demand in the southeastern United States', *GCB Bioenergy*, p. 6, 8:3, DOI: 10.1111/gcbb.12273 (accessed 30 Dec. 2016).
[18] Röder, M., Whittaker, C. and Thornley, P. (2015), 'How certain are greenhouse gas reductions from bioenergy? Life cycle assessment and uncertainty analysis of wood pellet-to-electricity supply chains from forest residues', *Biomass and Bioenergy,* 79, http://dx.doi.org/10.1016/j.biombioe.2015.03.030 (accessed 30 Dec. 2016). The study considered the impact of a wide range of factors, including different fuels used for drying.

article mentioned above, together with other estimates,[19] show considerable variability in methane emissions from stored sawdust, chips and pellets, and this can also vary depending on the storage conditions, whether the pile is covered, the ambient temperature and so on.

Similar supply-chain emissions are associated with fossil fuel extraction, from mining or drilling, processing and transport, and these should be taken into account in comparing alternative fuel scenarios. Again estimates vary, but studies suggest that an additional 5–10 per cent greenhouse gas emissions should be added to the combustion emissions from coal and about 30–35 per cent to those from gas (the figure is higher for gas because of the methane released during production).[20]

These variations in the technology in which the fuel is used, and in the life-cycle assessments, explain much of the difference in the greenhouse gas emission levels cited in various studies. Converting an old coal station to a modern biomass station or a remote rural community transiting from diesel-fired electricity generators to a biomass CHP plant using locally sourced feedstock might reduce carbon emissions over the entire life cycle of the system (depending on factors such as the type of feedstock and its impact on the forest). But these are limited examples; in most circumstances, comparing technologies of similar ages, it can be assumed that the use of woody biomass for energy releases higher levels of emissions than coal, and considerably higher levels than gas, as shown by the emission levels from Drax and Schiller quoted above.

This is only part of the picture, however, of the climate impact of woody biomass. The impacts will also vary with the type of woody biomass used, with what would have happened to it if it had not been burnt for energy and with what happens to the forest from which it was sourced. These questions are explored in the sections below.

Biomass energy feedstocks

Several different types of wood are commonly burnt for energy. The impact of their use on net carbon emissions, and therefore on the climate, depends partly on what would otherwise have been done with them if they had not been burnt for energy.

Mill residues

Mill residues are sides, bark, shavings, sawdust, trim ends, offcuts and so on produced as waste in sawmills; they typically amount to 45–55 per cent of the volume of timber entering the mill. Many years ago these were often burnt as waste, or sometimes disposed of in landfill, but now they are generally in demand for fibre products such as particleboard (e.g. MDF) or for use in pulp mills or for energy, either on-site in the sawmill or in biomass energy facilities elsewhere.

If the mill residues would otherwise have been burnt as waste or landfilled, or left to decay, it makes sense to use them for energy as the carbon content of the residues would be released into the atmosphere anyway as carbon dioxide and methane. If they would otherwise have been used for

[19] See, for example, Svedberg, U., Samuelsson, J. and Melin, S. (2008), 'Hazardous Off-Gassing of Carbon Monoxide and Oxygen Depletion during Ocean Transportation of Wood Pellets', *Annals of Occupational Hygiene,* pp. 259–66 (which showed methane concentrations in the holds of ships transporting pellets varying between 216 and 956 parts per million (ppm), 52:4, DOI: 10.1093/annhyg/men013 (accessed 30 Dec. 2016); and Zilkha Biomass Energy (2013), 'Cofiring Zilkha Black® Pellets', presentation at 3rd IEA CCC Cofiring Biomass with Coal Workshop, June 2013, which included figures of 275 ppm for white pellets (compared to about 50 ppm for black pellets) after 20 days' storage in laboratory jars.
[20] See, for example, Spath, P. L., Mann, M. K. and Kerr, D. R. (1999), *Life Cycle Assessment of Coal-fired Power Production,* Golden, CO: US National Renewable Energy Laboratory, DOI: 10.2172/12100 (accessed 30 Dec. 2016); Fulton, M. et al. (2011), *Comparing Life-Cycle Greenhouse Gas Emissions from Natural Gas and Coal,* Deutsche Bank, https://www.db.com/cr/en/docs/Natural_Gas_LCA_Update_082511.pdf (accessed 27 Dec. 2016).

wood products, however, using them for energy will result in increased carbon emissions equal to the difference between the emissions from combustion and the supply chain (collection, transport and processing such as pelletizing) and combustion and supply-chain emissions from the fossil fuels replaced (plus any impacts from the manufacturers using alternative sources of wood). A full life-cycle analysis would be needed to calculate the precise impact in any given scenario. Using mill residues locally for energy in the sawmill would have the lowest impact, as supply-chain emissions are minimized.

Forest residues

Forest residues (or 'slash') are the parts of harvested trees that are left in the forest after log products have been removed, including stumps, tops and small branches, and pieces too short or defective to be used. These can amount to as much as 40–60 per cent of the total tree volume. Sometimes forest residues may be burnt as waste, but more frequently they are left to rot in the forest or at the roadside. They can be used for energy and can be made into pellets, but this can cause problems in biomass plants (particularly when co-fired with coal) because of their high ash, dirt and alkali salt content, which accelerates corrosion of the boilers.

The impact on overall carbon emissions from using forest residues for energy depends partly on the rate at which they would have decayed and released carbon dioxide and methane into the atmosphere, which varies with factors such as the local climate, the type of soil and the amount of water present. All else being equal, decay rates tend to be faster in wet conditions. In the US, the majority of logging residue decay half-lives are 50 years or less. While under warm conditions (such as in much of the southeastern US) decay half-lives are generally less than 20 years, under cooler conditions half-lives of 100 years or longer have been reported.[21] A study of forest-residue decay in Finland found significant differences between types of residue (branches decayed far more quickly than stumps, for example) and between the southern and northern (and much colder) parts of the country.[22] The European Commission Joint Research Centre has reported decay rates varying between 40 per cent per year for needles and twigs, 11.5 per cent a year for branches in temperate climates and 2 per cent a year for coarse deadwood.[23]

> Many studies have shown that the removal of forest residues reduces both soil carbon storage and nutrient availability, which in turn leads to a fall in site fertility and tree growth, thereby reducing carbon storage in tree biomass in the long term.

The slower the decay rate the larger will be the net increase in carbon emissions from the use of residues for energy in the short and medium term, as the carbon is released immediately on combustion rather than being trapped in the residue. The net impact gradually falls over time as the residues would have rotted and released carbon.

These decay rates by themselves understate the impact of using forest residues for energy, however, as their removal may also have significant impacts on levels of soil carbon and on rates of tree growth.

[21] Miner, R. A. et al. (2014), 'Forest Carbon Accounting Considerations in US Bioenergy Policy', *Journal of Forestry,* 112:6, p. 9, https://doi.org/10.5849/jof.14-009 (accessed 27 Dec. 2016).
[22] Repo, A. (2015), *Climate impacts of bioenergy from forest harvest residues,* Aalto University. https://aaltodoc.aalto.fi/bitstream/handle/123456789/15923/isbn9789526061887.pdf? (accessed 27 Dec. 2016).
[23] Marelli, L. and Giuntoli, J. (2016), 'Assessing climate change mitigation potential of bioenergy technologies', presentation to European Commission bioenergy stakeholder conference, Brussels, 12 May 2016.

Many studies have shown that the removal of forest residues reduces both soil carbon storage and nutrient availability, which in turn leads to a fall in site fertility and tree growth, thereby reducing carbon storage in tree biomass in the long term.[24] The reduction in soil nutrients may also necessitate the use of fertilizers, with additional impacts on greenhouse gas emissions.[25] If these impacts are taken into account, the use of forest residues for energy may result in much larger increases in net carbon emissions, though this will depend partly on the proportion of residues removed. It should also be noted that the dynamics of soil carbon, including the amount of carbon from residues sequestered in the soil over time, and how much may be released due to harvesting, are not yet fully understood, and further research would be helpful.[26]

Roundwood

Compared to residues, the burning of roundwood (i.e. wood in its natural state as felled, including stemwood – the wood above ground – and stumps, which are sometimes classified as residues) for energy, represents the removal of growing forest carbon stock. Some of this roundwood may derive from other harvesting operations, or from additional fellings specifically for use as energy (through, for example, an increase in the area harvested annually or an increase in the intensification of felling, including clear-cutting) or from the diversion of harvested wood from other uses.

As with other types of wood, the impact on carbon emissions depends on what would have happened to the roundwood in the absence of use for energy – whether it would have been left growing, or harvested for some other use, or burnt or left to rot as otherwise unmerchantable, i.e. not fit for sale, parts of a harvest. In general, however, the net increase in carbon emissions will be much higher than from the use of mill or forest residues, as it includes not only the higher volume of emissions from burning biomass compared to burning fossil fuels but also the carbon emissions that would otherwise have been sequestered by the growing tree. (See below in this chapter for a discussion of carbon absorption by mature trees.)

Thinnings – the removal of selected trees or rows to allow stronger growth of the remaining trees, or to reduce the risk of fire – is one source of roundwood, though in the southeastern US the volume of thinnings has fallen in the last 20 years as plantation management has tended towards planting at lower densities.[27] However, studies suggest that the use of thinnings even from fire-prone forests do not reduce net greenhouse gas emissions for decades.[28] One study found that the use of thinnings for energy reduced carbon stocks in the forest, compared to leaving the forest alone, over 50 years.[29]

The increase in carbon emissions will also be high if roundwood is diverted from use in wood products such as panels or furniture or construction timber, as the carbon is emitted immediately rather than being fixed for years or decades. The competition for the raw material may also tend to

[24] See, for example, Buchholz, T. et al. (2014), 'Mineral soil carbon fluxes in forests and implications for carbon balance assessments', *GCB Bioenergy,* 6:4, DOI: 10.1111/gcbb.12044 (accessed 27 Dec. 2016); Achat, D. L. et al. (2015), 'Quantifying consequences of removing harvesting residues on forest soils and tree growth – A meta-analysis', *Forest Ecology and Management,* 348, http://dx.doi.org/10.1016/j.foreco.2015.03.042 (accessed 27 Dec. 2016); Achat, D. L. et al. (2015), 'Forest soil carbon is threatened by intensive biomass harvesting', *Nature Scientific Reports*, 5, DOI:10.1038/srep15991 (accessed 27 Dec. 2016).
[25] Schulze, E.-D. et al. (2012), 'Large-scale bioenergy from additional harvest of forest biomass is neither sustainable nor greenhouse gas neutral', *GCB Bioenergy*, 4:6, DOI: 10.1111/j.1757-1707.2012.01169.x (accessed 27 Dec. 2016).
[26] See, for example, Lamers, P. and Junginger, M. (2013), 'The "debt" is in the detail: A synthesis of recent temporal forest carbon analyses on woody biomass for energy', *Biofuels Bioproducts and Biorefining*, 7:4, DOI: 10.1002/bbb.1407 (accessed 27 Dec. 2016); 'Re: Burning wood from Southern US forests to generate electricity in Europe' Letter from US academics to European Commissioner for Energy Günther Oettinger, 30 August 2013, https://www.nrdc.org/sites/default/files/ene_13090603a.pdf (accessed 27 Dec. 2016).
[27] Strange Olesen, A. et al. (2015), *Environmental Implications of Increased Reliance of the EU on Biomass from the South East US*, p. 40.
[28] See, for example, Hudiburg, T. et al. (2011), 'Regional carbon dioxide implications of forest bioenergy production', *Nature Climate Change,* 1, DOI:10.1038/nclimate1264 (accessed 27 Dec. 2016).
[29] Clark, J. et al. (2011), *Impacts of thinnings on carbon stores in the PNW: A plot level analysis*, Corvallis, OR: Oregon State University, https://www.nrdc.org/sites/default/files/ene_13041704a.pdf (accessed 27 Dec. 2016).

increase prices, which may lead to increased rates of harvesting, higher imports of wood products, substitution to non-wood products, and an increase in the rate of planting new forests. This depends, though, on the relative levels of demand; for example, there may be little competition in practice if the output of the competing industry is declining.

In 2015 a comprehensive review of the supply of woody biomass from the southeastern US to the EU found little evidence of any such diversion in practice, apart possibly for some sawmill residues.[30] Similarly, in 2016 a European Commission state aid investigation into the UK government's financial support for the conversion of the third unit at Drax from coal to biomass, triggered in part because of its potential impact on competition for wood, concluded that the increased demand from wood pellets 'could be fulfilled by the market without undue negative side-effects'.[31] Nevertheless, a number of wood-products industries have expressed concern over the distorting effect of subsidies for biomass energy on the market for the raw material on which they depend.[32]

Black liquor

Although black liquor is an important source of biomass energy in many countries, its climate impacts have received relatively little attention compared to those of other feedstocks. A waste product from the kraft pulping process, which digests pulpwood into paper pulp, black liquor comprises a solution of lignin residues, hemicellulose and the inorganic chemicals used in the process. Originally simply discharged into local watercourses (with major local environmental impacts), virtually all pulp and paper mills now burn black liquor in recovery boilers for energy, generating steam and recovering some of the chemicals used. Modern mills should be self-sufficient for energy; indeed, many produce a surplus of electricity for export to the local or national grid. New waste-to-energy methods involving gasification have the potential to achieve higher efficiencies than the conventional recovery boiler while also generating an energy-rich syngas, which can be used to generate electricity or be converted into methanol and other transport fuels.

Black liquor is very different from most other uses of biomass. It is in its entirety waste produced as a by-product of a wood-based industry, with no impact on forest carbon stock (separate from the impact of the pulp and paper industry). It is generated and used on-site, with no transport costs. If it was not burnt for energy, the pulp mills would face the task of disposing of a highly polluting substance. In general the use of black liquor should be economic without the need for subsidy, though in the US a tax loophole aimed at promoting alternative fuels has allowed paper companies to claim very substantial tax refunds for its use.[33] One study of the life-cycle impact of black liquor recovery on climate change concluded that greenhouse gas emissions were approximately 90 per cent lower than those for a comparable fossil fuel-based system.[34] From the point of view of analysis, it is highly regrettable that black liquor is often included alongside other types of solid biomass in reported statistics since its climate impact is clearly very different.

[30] Strange Olesen, A. et al. (2015), *Environmental Implications of Increased Reliance of the EU on Biomass from the South East US*, pp. 141–44.
[31] European Commission (2016), 'State aid: Commission authorises UK support to convert unit of Drax power plant from coal to biomass', 19 December 2016, http://europa.eu/rapid/press-release_IP-16-4462_en.htm (accessed 27 Dec. 2016).
[32] See, for example, American Forest and Paper Association (undated), 'Biomass and Renewable Energy Mandates', http://www.afandpa.org/issues/issues-group/biomass-and-renewable-energy-mandates (accessed 27 Dec. 2016); and RISI (2015), *An Analysis of UK Biomass Power Policy, US South Pellet Production and Impacts on Wood Fiber Markets*, Bedford, MA: RISI, http://docplayer.net/25281897-An-analysis-of-uk-biomass-power-policy-us-south-pellet-production-and-impacts-on-wood-fiber-markets-prepared-for-the-american-forest-paper.html (accessed 27 Dec. 2016).
[33] Hoffman, W. (2014), 'Black Liquor: The Loophole That Won't Quit', Tax Analysts, 9 April 2014 http://www.taxanalysts.org/content/black-liquor-loophole-wont-quit (accessed 27 Dec. 2016).
[34] Gaudreault, C. et al. (2012), 'Life cycle greenhouse gases and non-renewable energy benefits of kraft black liquor recovery', *Biomass and Bioenergy,* 46, http://dx.doi.org/10.1016/j.biombioe.2012.06.027 (accessed 27 Dec. 2016).

Feedstocks in use

The discussion earlier highlights the critical influence of the type of wood product used as feedstock. In general the use of residues and wastes is likely to result in a much smaller net increase in carbon emissions, or in some circumstances a reduction, compared to the use of roundwood.

Many of the models contained in studies of the impacts of using wood for energy (discussed further below) assume that residues are the main feedstock. In the model used in a 2012 paper, residues supplied 65 per cent of the woody biomass projected to be used for energy in 2015, and remained important beyond that unless constrained by policy.[35] Similarly, scenarios modelled in one 2015 study, which looked ahead to 2032, assumed that mill residues comprised 67 per cent of feedstock in a situation of low demand; additional harvesting (of pulpwood – debarked sections of stems 5–23 cm in diameter) provided 19 per cent.[36] In a situation of high demand, however, that study assumed that the supply of mill residues would not be sufficient and would only provide 36 per cent of feedstock; the proportion provided by additional harvesting was estimated as 36 per cent. Two other papers in 2013 and 2015 argued for using residues more intensively.[37] The second of these claimed a much greater potential for using forest residues in Sweden than the 20 per cent currently used for bioenergy.[38] As discussed above, however, greater use of forest residues seems likely to release more soil carbon and to reduce forest growth, thus increasing net carbon emissions.

Information provided by the biomass energy industry, including wood pellet companies, tends to emphasize the use of residues. For example, in its supply report for 2014 Drax reported that its feedstock mix included 37 per cent sawdust and sawmill residues, 29 per cent forest residues (which it defined as including low-grade wood) and 24 per cent thinnings.[39] For 2015–16 it reported 47 per cent sawmill residues, 26 per cent low-grade roundwood and forest residues, and 24 per cent thinnings.[40] Enviva, the largest US pellet producer, stresses its use of low-grade wood fibre (wood that would otherwise have been rejected from lumber mills), tops and limbs, chips made by suppliers in the forest out of low-grade wood and waste materials and commercial thinnings, alongside mill waste and residues.[41] Both companies tend to group 'low-grade wood' along with 'forest residues', though the impact on carbon emissions is not the same.

In contrast, however, in April 2015, in the prospectus accompanying its initial public offering, Enviva stated that:

> Our primary source of wood fiber is traditional pulpwood, which has historically exhibited less pricing volatility than other sources of wood fiber…we also procure industrial residuals (sawdust and shavings) and forest residuals (wood chips and slash), which have been more volatile historically in terms of price and supply but occasionally represent lower cost alternative inputs.[42]

NGOs in the US have identified cases where biomass energy companies have stated either that they regard waste and forest residues as unsuitable feedstocks in terms of quantity or quality, or both, or

[35] Daigneault, A., Sohngen, B. and Sedjo, R. (2012), 'Economic approach to assess the forest carbon implications of biomass energy', *Environmental Science and Technology*, p. 5668, 46:11, DOI: 10.1021/es2030142 (accessed 27 Dec. 2016).
[36] Wang, W. et al. (2015), 'Carbon savings with transatlantic trade in pellets', pp. 5–6.
[37] Lamers, P. and Junginger, M. (2013), 'The "debt" is in the detail', p. 382; Gustavsson, L. et al. (2015), 'Climate effects of bioenergy from forest residues in comparison with fossil energy', *Applied Energy,* 138.
[38] Gustavsson, L. et al. (2015), 'Climate effects of bioenergy from forest residues in comparison with fossil energy'.
[39] Drax (2015), *Biomass Supply 2014*, p. 6, DOI: 10.1016/j.apenergy.2014.10.013 (accessed 27 Dec. 2016).
[40] Drax (undated), 'Drax feedstock mix by fibre type for compliance year 2015–16', http://www.drax.com/sustainability/sustainability-reporting (accessed 27 Dec. 2016).
[41] Enviva (undated), 'Wood Fiber Resources', http://www.envivabiomass.com/wp-content/uploads/Enviva-Wood-Fiber-Resources.pdf (accessed 27 Dec. 2016).
[42] Enviva (2015), 'Prospectus', 28 April 2015, p. 131, http://www.sec.gov/Archives/edgar/data/1592057/000119312515155449/d808391d424b4.htm (accessed 27 Dec. 2016).

classify whole trees or whole-tree chips as 'waste'.[43] The Vyborgskaya pellet plant in Russia sources only logs, according to a corporate presentation in 2013 that did not mention either mill or forest residues.[44]

The European Commission's 2015 review of the supply of woody biomass from the southeastern US to the EU concluded that, while sawmill residues were in many ways the ideal source material for pellets, US mill residues were already almost entirely utilized by the biomass energy or other industries, and there was very limited room for expansion.[45] As noted earlier, the use of forest residues can cause problems in biomass plants because of their high ash, dirt and alkali salt content. Partly for this reason, the European Commission concluded that residues such as tops, limbs and other unmerchantable materials 'currently do not play a significant role' in the woody biomass supply chain. Various types of roundwood, mainly pulpwood but also larger sizes, were therefore the main source – typically about three-quarters – of the feedstock volume of large industrial pellet facilities.[46]

These findings are supported by other studies. One 2015 study suggested that 76 per cent of feedstock used to produce pellets in the southern US was pulpwood while mill residues and forest residues accounted for 12 per cent each.[47] A survey of forest resources in the US found that in 2011 less than 1 per cent of mill residues was not already used; 43 per cent was used for commercial fuel, 40 per cent for fibre products and the rest for other products.[48]

The question of the types of wood used for biomass energy has become one of the most bitterly contested issues in the debate over its impacts. NGOs have published reports claiming that pellet plants use whole trees extensively, including sourcing from harvesting specifically for energy use.[49] Where these are hardwoods – which provide up to 100 per cent of the feedstock for some of Enviva's pellet plants, according to information provided by the company in 2015 – this increases net carbon emissions over time, as hardwoods take much longer to grow back than softwoods.[50] The pellet and biomass energy companies counter that where whole trees are used they tend only to be dead or diseased or otherwise unmerchantable trees that would have no other use – though trees that would not qualify as high-quality sawtimber could nevertheless be used for pulp, panels or laminated products.

This is important because of the significant difference these categories can make to the impact on net carbon emissions. As discussed above, the impacts from using mill or forest residues are much lower than those for material from growing trees harvested specifically for energy use, since in the latter case carbon absorption from growing trees is foregone (along with the higher carbon emissions from using biomass instead of fossil fuels). In 2015 an analysis of the feedstock sources from the southern US reported by Drax for 2014 (which differentiated between 'forest residues' and 'low-grade wood' – as noted, the two are combined in Drax's figures) used the UK government's BEaC scenarios

[43] See, for example, Booth, M. and Bitov, K. (2013), *Analysis of Risks and Corporate Disclosures Regarding Environmental and Climate Considerations in the Biomass Power Sector,* Partnership for Policy Integrity, http://www.pfpi.net/wp-content/uploads/2013/11/PFPI-report-to-SEC-on-bioenergy-Nov-20-2013.pdf (accessed 27 Dec. 2016); Partnership for Policy Integrity and Dogwood Alliance (2016), *Carbon Emissions and Climate Change Disclosure by the Wood Pellet Industry – A Report to the SEC on Enviva Partners LP*, https://www.dogwoodalliance.org/wp-content/uploads/1999/11/Report-to-SEC-on-Enviva-March-14-2016.pdf (accessed 27 Dec. 2016).
[44] Dale, A. (2013), 'Wood Pellets from Russia', presentation to Wood Pellet Association of Canada, 18–20 November 2013, http://www.pellet.org/images/21_-_Arnold_Dale_-_From_Russia_with_Love_2013.pdf (accessed 27 Dec. 2016).
[45] Strange Olesen, A. et al. (2015), *Environmental Implications of Increased Reliance of the EU on Biomass from the South East US,* pp. 95–96.
[46] Ibid.
[47] RISI (2015), *An Analysis of UK Biomass Power Policy, US South Pellet Production and Impacts on Wood Fiber Markets*, p. 20.
[48] Oswalt, S. N. et al. (2014), *Forest Resources of the United States, 2012: a technical document supporting the Forest Service 2015 update of the RPA Assessment,* p. 21, Washington, DC: US Department of Agriculture, Forest Service, https://www.srs.fs.usda.gov/pubs/gtr/gtr_wo091.pdf (accessed 27 Dec. 2016).
[49] See, for example, reports produced by Dogwood Alliance, https://www.dogwoodalliance.org/campaigns/bioenergy/bioenergy-reports/), the Natural Resources Defense Council, https://www.nrdc.org/issues/support-renewable-energy-protects-wild, and the Southern Environmental Law Center, https://www.southernenvironment.org/cases-and-projects/biomass-energy-in-the-south.
[50] Partnership for Policy Integrity and Dogwood Alliance (2016), *Carbon Emissions and Climate Change Disclosure by the Wood Pellet Industry*, p. 29.

(see below) to calculate net carbon emissions.[51] This concluded that Drax's emissions were at least 2,677 kg CO_2-eq/MWh for a scenario in which 80 per cent of feedstock derived from additional biomass harvests in southeastern US hardwoods, with the remainder coming from sawmill or forest residues; or at least 1,227 kg CO_2-eq/MWh for a scenario assuming 48 per cent of the feedstock derived from forest residues that would otherwise have decayed, with the remainder sourced from sawmill residues (17 per cent) and additional biomass harvests (35 per cent). In each case these emissions levels are significantly higher than those from coal. A Drax spokesperson commented that the study was based 'on a mountain of assumptions… based on an outlandish scenario' and insisted that the hardwood sourced by Enviva for its pellets was a residue of normal commercial operations.[52]

Part of the problem is the lack of clear definitions of the term 'forest residues'. The EU Renewable Energy Directive, for example, does not define it. In the UK, the energy regulator, Ofgem, defines forestry residues as material 'derived from "virgin wood"', including:

> all raw materials collected directly from the forest, whether or not as a result of thinning or logging activities. This may include (but is not limited to) materials such as tree tops, branches, brash, clippings, trimmings, leaves, bark, shavings, woodchips and saw dust from felling.[53]

'Virgin wood' is defined as:

> timber from whole trees and the woody parts of trees including branches and bark derived from forestry works, woodland management, tree surgery and other similar operations. It does not include clippings or trimmings that consist primarily of foliage (though these may be forestry residues).[54]

These definitions are confusing and potentially overlapping: whole trees, or logs, could fall under the definition of forest residues or of virgin wood despite their very different impacts on emissions. Similarly, the definitions of logging residues by the US Forest Service and US Department of Energy can include whole trees. In one 2016 report the latter defined logging residues as 'trees not meeting merchantable timber specifications and tree components, such as limbs, tops, and cull logs'.[55] These imprecise definitions are not helpful in resolving the debate over climate impacts.

Biomass and the forest carbon cycle

It is not disputed that burning woody biomass for energy produces emissions of carbon dioxide and other greenhouse gases. But the argument is often made that since these carbon emissions are absorbed as part of the natural forest cycle of growth and regrowth, they should therefore be counted as zero at the point of combustion (in other words, that the discussion above about the climate impact of different types of feedstocks is irrelevant). Many studies of the benefits of biomass energy, including the ones cited above, assume just that. Similarly, national sustainability criteria for woody biomass that set minimum levels of greenhouse gas savings compared to the fossil fuels they replace ignore the emissions produced during combustion and consider only supply-chain emissions from harvest, processing and transport (see Chapter 3). This is what lies behind claims such as one about biomass

[51] Buchholz, T. and Gunn, J. (2015), *Carbon Emission Estimates for Drax biomass powerplants in the UK sourcing from Enviva Pellet Mills in U.S. Southeastern Hardwoods using the BEAC model,* Pleasanton, CA: Spatial Informatics Group.
[52] ENDS Waste and Bioenergy (2015), 'Drax rejects carbon criticism', 3 June 2015, http://www.endswasteandbioenergy.com/article/1349937/drax-rejects-carbon-criticism (accessed 27 Dec. 2016).
[53] Ofgem (2016), *Renewables Obligation: Sustainability Criteria Guidance,* Table 11, pp. 83–84, https://www.ofgem.gov.uk/system/files/docs/2016/03/ofgem_ro_sustainability_criteria_guidance_march_16.pdf (accessed 27 Dec. 2016).
[54] Ibid, Table 10, pp. 81–82.
[55] US Department of Energy (2016), *2016 Billion-Ton Report: Advancing Domestic Resources for a Thriving Bioeconomy, Volume 1: Economic Availability of Feedstocks*, Washington, DC: US Department of Energy, p. 127 https://energy.gov/sites/prod/files/2016/12/f34/2016_billion_ton_report_12.2.16_0.pdf (accessed 27 Dec. 2016).

representing an 80 per cent emissions saving compared to coal.[56] The argument may also be used that, if waste (including residues) is used as the feedstock, emissions can be considered to be zero, since no additional harvesting is involved.

This argument takes various forms. The most extreme version is that woody biomass emissions should count as zero because carbon has already been absorbed during the growth of the trees that are logged and burnt. As one study argued in 2011, 'Those trees have been gathering carbon (some of which is from the combustion of fossil fuels) for… 30 years… We have accrued a dividend. We can then derive a benefit from that dividend by using those trees for energy.'[57] This argument implies that, once they have grown, what happens to trees later – whether they are left to grow further, or harvested and made into wood products, or harvested and burnt for energy – somehow makes no difference to carbon concentrations in the atmosphere. This is obviously not the case.

A similar argument is that, as long as the trees are harvested from a forest that is sustainably managed, their carbon emissions should be considered to be zero: effectively, forest growth, replacing the logged trees, cancels out the emissions released when burnt. The description of the IEA's Bioenergy Task 38 on Climate Change Effects of Biomass and Bioenergy Systems, for example, includes the statement that:

> Biomass fuels can have higher carbon emission rates (amount of carbon emitted per unit of energy) than fossil fuels (e.g. oil, or natural gas) due to generally lower energy density of biomass. This fact is only relevant, when biomass fuels are derived from unsustainable land-use practices (the carbon emissions from combustion of sustainable biomass are excluded from calculations because they are counterbalanced by the uptake of CO_2 as the feedstock is grown i.e. the photosynthetic and combustion stages of the life cycle are carbon neutral).[58]

As mentioned earlier, this argument must assume that whatever happens to the trees after they are harvested (assuming sustainable management, i.e. that forest growth replaces the forest carbon lost when logged) makes no difference to carbon concentrations in the atmosphere: burning them for energy is the same as fixing the carbon in wood products. Again, as above, this is clearly wrong. Furthermore, this argument ignores the carbon sequestration forgone from harvesting the trees: they would have continued to grow and absorb carbon if left un-harvested, and the uptake of carbon therefore falls when they are logged, whether or not the forest is sustainably managed. This is not true only if the forest grows *more slowly* in the absence of logging for energy, or if harvesting promotes *additional growth* fast enough to replace the carbon emitted when burnt; both issues are discussed below.

The third version of the argument discounts any link between the trees, or parts of trees, burnt for energy and the forest stand, or the forest, from which they derive, and asserts that as long as the forest as a whole or forests in general are expanding, emissions from combustion can be ignored. Although globally deforestation is continuing, this is not the case in Europe or North America, which are currently the main sources of wood for energy in modern technologies and are seeing an increase in forest cover. This fact is sometimes cited as evidence that the use of wood from these areas for energy is sustainable: if total forest cover is increasing, more carbon is being absorbed, which offsets the additional carbon emitted to the atmosphere when wood from those areas is burnt.[59]

[56] For example, according to a Drax spokesperson, 'Using the latest biomass technology has resulted in an over 80 per cent carbon saving compared to coal. This independently verified data factors in the full carbon costs from across the whole supply chain – including harvesting, processing and transportation.' Timperley, J. (2016), 'Is biomass really more polluting than coal?', Business Green, 17 October 2016, http://www.businessgreen.com/bg/analysis/2474217/is-biomass-really-more-polluting-than-coal (accessed 27 Dec. 2016).
[57] Strauss, W. (2011), 'How Manomet Got It Backwards: Challenging the 'Debt-Then-Dividend' Axiom', Biomass Magazine, 22 June 2011, http://biomassmagazine.com/articles/5621/how-manomet-got-it-backwards-challenging-the-undefineddebt-then-dividendundefined-axiom (accessed 27 Dec. 2016).
[58] IEA Bioenergy Task 38 (2013), 'Description of IEA Task 38'.
[59] Evans, S. (2015), 'Investigation: Does the UK's biomass burning help solve climate change?', Carbon Brief, 11 May 2015, https://www.carbonbrief.org/investigation-does-the-uks-biomass-burning-help-solve-climate-change (accessed 27 Dec. 2016).

Again, this ignores the carbon absorption forgone when the trees are harvested and burnt as well as the counterfactual regarding what would have happened if the trees had not been harvested and burnt for energy. There is no automatic link between the increase in forest growth and burning wood for biomass – particularly when the argument depends on expansion in forests entirely unconnected to those from which the wood for energy is harvested – and there is no reason to assume that, globally, forests would grow more slowly in the absence of the biomass industry.

Carbon absorption, forest growth and forest age

The main argument for a positive impact of burning woody biomass is if the forest area expands as a direct result of harvesting wood for energy, and if the additional growth exceeds the emissions from combustion of biomass. Various models have predicted that this could be the case: that the additional income from selling wood for energy (even if this is only part of the harvest) may encourage forest owners to invest more in their forests and plant a greater area.[60] These are models, however, rather than real-world observations, and it is not clear that this phenomenon is actually being observed. As can be seen in Table 3, the area of commercial timberland (i.e. forest land available for the production of forest products) in the five southeastern US states where most US wood pellet mills are found did not change significantly between 2011 and 2014, a period during which the wood pellet and biomass industries were both expanding.

Table 3: Timberland area of southeastern US states, 2011 and 2014

	Area of timberland (000 ha)		
State	2011	2014	Change 2011–14
Alabama	9,279	9,320	+0.44%
Georgia	9,874	9,776	–0.99%
North Carolina	7,316	7,331	+0.21%
South Carolina	5,237	5,180	–1.10%
Virginia	6,198	6,228	+0.48%

Source: US Forest Service (undated), 'Forest Inventory and Analysis – Southern Research Station', http://srsfia2.fs.fed.us/states/state_information.shtml.

If anything, the evidence suggests the opposite. In 2014, for example, the US Forest Service reported that while forest hardwood inventories were expected to continue increasing to 2020, even as bioenergy demand increased, the rate of growth of forest carbon stocks would be lower as a result of demand for biomass for energy. It concluded: 'Even assuming full utilisation of mill residues and increased utilisation of logging residues, harvest of pine and hardwood non-sawtimber feedstock increases… hardwood inventories continue to increase although these end at lower levels' than without new bioenergy demand.[61]

In addition, the models always assume that younger trees grow faster and therefore absorb more carbon than older, more mature trees; as one study stated, 'the CO_2 uptake in old forests is low, and

[60] See, for example, Daigneault, A., Sohngen, B. and Sedjo, R. (2012), 'Economic approach to assess the forest carbon implications of biomass energy'; Miner, R. A. et al. (2014), 'Forest Carbon Accounting Considerations in US Bioenergy Policy'; Wang, W. et al. (2015), 'Carbon savings with transatlantic trade in pellets'; Hektor, B., Backéus, S. and Andersson, K. (2016), 'Carbon balance for wood production from sustainably managed forests', *Biomass and Bioenergy*, 93, DOI: 10.1016/j.biombioe.2016.05.025 (accessed 27 Dec. 2016).
[61] Abt, K. L., et al. (2014), *Effect of Policies on Pellet Production and Forests in the U.S. South: A Technical Document Supporting the Forest Service Update of the 2010 RPA Assessment,* Washington, DC: US Department of Agriculture, https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs202.pdf (accessed 27 Dec. 2016).

in very old stands the CO_2 is even negative' (because of the greater likelihood of carbon losses due to fire, storms or insects).[62] Thus it is argued that harvesting mature trees and replanting will increase the rate of carbon uptake. Studies suggest, however, that this is not true, particularly in old-growth forests, though it may be in plantations (possibly because of lower soil nutrient availability in plantations compared to natural forests).

Many studies, particularly some conducted recently, have shown that mature trees absorb more carbon than younger trees, mainly because of their much higher number of leaves, which enable greater absorption of carbon dioxide from the atmosphere.[63] As a 2014 study concluded:

> for most species mass growth rate increases continuously with tree size. Thus, large, old trees do not act simply as senescent carbon reservoirs but actively fix large amounts of carbon compared to smaller trees; at the extreme, a single big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree.[64]

According to one 2008 study:

> [the] commonly accepted and long-standing view that old-growth forests are carbon neutral… was originally based on ten years' worth of data from a single site. It is supported by the observed decline of stand-level net primary production with age in plantations, but is not apparent in some ecoregions.[65]

Although the rate of carbon uptake does tend to decline with the age of the tree, it found that 'in forests between 15 and 800 years of age, net ecosystem productivity (the net carbon balance of the forest including soils) is usually positive.'[66] Several studies suggest that the rate of carbon uptake has accelerated in recent years with the increasing concentration of carbon dioxide in the atmosphere. Since trees are prone to disease and pests, the high rate of carbon uptake of older trees is somewhat offset by their higher mortality rates, but only partially, and it should be possible to reduce this by management for conservation (e.g. removing diseased or dead trees).

This conclusion is supported by other studies suggesting that, far from accelerating carbon uptake, harvesting may in fact bring it to a temporary halt. One reviewing the impacts of forest disturbances (including harvesting, fires, storms and insect infestation) throughout the US concluded that in most cases the forest did not return to its status as a carbon sink for at least 10, and sometimes as much as 20, years, partly due to the large soil carbon losses associated with the event.[67] Similarly, a model-based study of forest carbon storage in the northeastern US compared different types of forest management and concluded that the highest rate of carbon uptake and storage was achieved simply by leaving the forest alone:

[62] Hektor, B., Backéus, S. and Andersson, K. (2016), 'Carbon balance for wood production from sustainably managed forests', p. 3.
[63] See, for example, Luyssaert, S. et al. (2008), 'Old-growth forests as global carbon sinks', *Nature,* 455, DOI:10.1038/nature07276 (accessed 27 Dec. 2016); Lewis, S. et al. (2009), 'Increasing carbon storage in intact African tropical forests', *Nature,* 457, 19 February 2009, DOI:10.1038/nature07771 (accessed 27 Dec. 2016); Bellassen, V. and Luyssaert, S. (2014), 'Carbon sequestration: Managing forests in uncertain times', *Nature,* 506, 12 February 2014, DOI: 10.1038/506153a (accessed 27 Dec. 2016); Stephenson, N. L. et al. (2014), 'Rate of tree carbon accumulation increases continuously with tree size', *Nature* 507, DOI:10.1038/nature12914 (accessed 27 Dec. 2016); Craggs, G. (2016), *The Role of Old-Growth Forests in Carbon Sequestration,* Dalkeith: Future Directions International, http://www.futuredirections.org.au/publication/role-old-growth-forests-carbon-sequestration (accessed 27 Dec. 2016). Over 60 studies showing the same phenomenon are summarized in CO_2 Science (2014), 'Forests (Growth Rates of Old vs. Young Trees) – Summary', http://www.co2science.org/subject/f/summaries/forestold.php (accessed 27 Dec. 2016).
[64] Stephenson, N. L. et al. (2014), 'Rate of tree carbon accumulation increases continuously with tree size'.
[65] Luyssaert, S. et al. (2008), 'Old-growth forests as global carbon sinks', p. 213.
[66] Ibid.
[67] Amiro, B. D. et al. (2010), 'Ecosystem carbon dioxide fluxes after disturbance in forests of North America', *Journal of Geophysical Research*, 115:G4, DOI: 10.1029/2010JG001390 (accessed 27 Dec. 2016).

> The results supported both our first hypothesis that passive management sequesters more carbon than active management, as well as our second hypothesis that management practices favoring lower harvesting frequencies and higher structural retention sequester more carbon than intensive forest management.[68]

Most of the models assuming that the production of wood for energy accelerates carbon uptake also assume that much of the rapid growth is achieved by replacing old-growth forests with plantations, most commonly of relatively fast-growing pine species.[69] As well as causing higher carbon emissions from the loss of mature trees, at the point of harvest and in terms of foregone future carbon sequestration, this is also highly likely to have negative impacts on biodiversity and habitats.[70] This reinforces the need to protect old-growth forests, not only for their value for biodiversity and amenity but also for their role as a significant carbon sink.

The temporal dimension: the carbon payback period

A different way of looking at the climate impacts of biomass energy is to consider the temporal dimension of the issue. It can be argued that the carbon dioxide emitted by burning woody biomass for energy is indeed absorbed from the atmosphere by forest growth, but this takes place only over time, a factor ignored by the arguments discussed earlier.

Following this argument, the carbon dioxide (and other greenhouse gases) released by the burning of woody biomass for energy, along with their associated life-cycle emissions, create what is termed a 'carbon debt' – i.e. the additional emissions caused by burning biomass instead of the fossil fuels it replaces, plus the emissions absorption foregone from the harvesting of the forests.[71] Over time, regrowth of the harvested forest removes this carbon from the atmosphere, reducing the carbon debt. The period until carbon parity is achieved (i.e. the point at which the net cumulative emissions from biomass use are equivalent to those from a fossil fuel plant generating the same amount of energy) is usually termed the 'carbon payback period'. After this point, as regrowth continues biomass may begin to yield 'carbon dividends' in the form of atmospheric greenhouse gas levels lower than would have occurred if fossil fuels had been used. Eventually carbon levels in the forest return to the level at which they would have been if they had been left unharvested. (Some of the literature employs the term 'carbon payback period' to describe this longer period, but it is more commonly used to mean the time to parity with fossil fuels; this meaning is used in this paper.)

The factors affecting the length of the carbon payback period are the same as those discussed above: the level of emissions produced during harvesting, collecting, processing, transporting and burning the biomass compared to the fossil fuels that it replaces, together with the counterfactual about what would have happened to the wood if it had not been used for energy and to the forest from which it was sourced.[72]

[68] Nunery, J.S., and Keeton, W.S. (2010), 'Forest carbon storage in the northeastern United States: Net effects of harvesting frequency, post-harvest retention, and wood products', *Forest Ecology and Management*, 259:8, http://dx.doi.org/10.1016/j.foreco.2009.12.029 (accessed 27 Dec. 2016).
[69] Including Hektor, B., Backéus, S. and Andersson, K. (2016), 'Carbon balance for wood production from sustainably managed forests'; Jonker J. G. G., Junginger, M. and Faaij, A. (2014), 'Carbon payback period and carbon offset parity point of wood pellet production in the South-eastern United States'.
[70] See, for example, Strange Olesen, A. et al. (2015), *Environmental Implications of Increased Reliance of the EU on Biomass from the South East US*, pp. 127–31.
[71] 'Carbon debt' is not a precise term. It is sometimes used instead to refer to the period it takes for growing trees to recapture the emissions released from an equivalent amount of carbon. The meaning used here is taken from Mitchell, S. R., Harmon, M. E. and O'Connell, K. E. B. (2012), 'Carbon debt and carbon sequestration parity in forest bioenergy production', *GCB Bioenergy,* 4:6, DOI: 10.1111/j.1757-1707.2012.01173.x (accessed 27 Dec. 2016).
[72] For an overview of many of these factors, see Agostini, A., Giuntoli, J. and Boulamanti, A. (2013), *Carbon accounting of forest bioenergy.*

Following the discussion earlier, the carbon payback period for mill residues can be assumed to be very low as no additional felling is involved. If the residues would otherwise have been burnt as waste the payback period may be zero. The carbon payback period for forest residues is more complex, depending on the rate at which they would decay if left to rot in the forest, and on the impacts on forest growth of the removal of residues; but again no additional felling is involved. In neither case is there any additional regrowth of forests; the carbon debt is repaid over time from the lower emissions from the residues not being burnt as waste or decaying.

Since the burning of roundwood in general represents the removal of growing forest carbon stock, the carbon payback period will be longer as it includes the foregone future absorption of carbon emissions. This is particularly the case in forest systems with relatively slow growth rates – such as hardwoods, common in the southeastern US – and will also vary depending on the age of the trees, whether they are natural growth or plantations and the extent to which the forest has been managed before the harvest.[73] As discussed above, harvesting may also release significant volumes of soil carbon.[74]

If wood is diverted from alternative uses, such as construction or wood panels or paper, the carbon payback period may be very high as carbon can be fixed in some of these products for decades – though, as discussed above, there is little evidence of this taking place so far.

Many attempts have been made to estimate average payback periods.[75] Eight different studies carried out between 2009 and 2012 in Europe and North America, summarized in a 2012 report, produced estimated payback periods between zero (for the use of fellings residues to replace coal for electricity) to 459 years (for the use of wood from old-growth forests to produce ethanol for transport fuel).[76] The scenarios using residues, branches, thinnings or stumps all showed payback periods between zero and 74 years, with most less than 25 years. Where old-growth or second-growth trees were assumed to be used, the payback period was much longer.

Similarly, a 2013 survey of studies of the replacement of fossil fuel-generated electricity reported payback periods between zero and 400 years.[77] The use of residues and slash saw payback periods between zero and 44 years, with the lowest periods for the replacement of coal and the highest for natural gas. The lowest payback periods for the use of roundwood was between zero and 105 years in the case of additional fellings in previously unmanaged forests, or 12–46 years for the use of thinnings and additional fellings from existing plantations with a 20–25 year rotation, in each case replacing coal. A 2014 study found some greenhouse gas benefits from the use of forest residues with payback periods up to 25 years, while the use of whole trees, whether from thinnings, reduced-impact logging or short-rotation forestry, saw little or no savings over 50 years.[78]

[73] Gunn, J. S., Ganz, D. V. and Keeton, W S. (2012), 'Biogenic vs. geologic carbon emissions and forest biomass energy production', *GCB Bioenergy,* 4:3, DOI: 10.1111/j.1757-1707.2011.01127.x (accessed 27 Dec. 2016).
[74] Buchholz T. et al. (2014), 'Mineral soil carbon fluxes in forests and implications for carbon balance assessments'.
[75] See, for example, Walker, T. et al. (2010), *Biomass Sustainability and Carbon Policy Study,* Brunswick, ME: Manomet Center for Conservation Sciences, http://www.mass.gov/eea/docs/doer/renewables/biomass/manomet-biomass-report-full-hirez.pdf (accessed 27 Dec. 2016); Searchinger, T. (2012), 'Global Consequences of the Bioenergy Greenhouse Gas Accounting Error', in Inderwildi, O. and King, D. (eds) (2012), *Energy, Transport and the Environment,* London: Springer-Verlag; and Bowyer, C. et al. (2012), *The GHG Emissions Intensity of Bioenergy: Does bioenergy have a role to play in reducing Europe's GHG emissions?,* London: Institute for European Environmental Policy, http://www.ieep.eu/assets/1008/IEEP_-_The_GHG_Emissions_Intensity_of_Bioenergy_-_October_2012.pdf (accessed 27 Dec. 2016).
[76] See Agostini, A., Giuntoli, J. and Boulamanti, A. (2013), *Carbon accounting of forest bioenergy*, pp. 43–44.
[77] Lamers, P. and Junginger, M. (2013), 'The "debt" is in the detail'.
[78] Baral, A. and Malins, C. (2014), *Comprehensive Carbon Accounting for Identification of Sustainable Biomass Feedstocks,* Washington, DC: International Council on Clean Transportation, http://www.theicct.org/sites/default/files/publications/ICCT_carbonaccounting-biomass_20140123.pdf (accessed 27 Dec. 2016).

In 2014 the UK Department of Energy and Climate Change published a comprehensive assessment of the climate impacts of imports of biomass from the US (the main source of woody biomass for UK consumption) – the Bioenergy Emissions and Counterfactuals (BEaC) calculator.[79] Of the 29 scenarios analysed, those that involved utilizing residues that would otherwise have been burnt as waste, or newly established tree plantations on low-carbon land resulted in low net carbon emissions and short payback periods. In contrast, scenarios that involved harvesting additional roundwood from naturally growing forests or converting forests into plantations resulted in high or very high emissions (depending on the rotation length and hence carbon stocks of the forests and plantations). Of the 29 scenarios, 11 resulted in net emissions higher than using natural gas, and five of those had net emissions higher than using coal. For some types of biomass, such as additional fellings in already managed forests, the carbon payback period was many decades, perhaps even centuries.

The BEaC report was criticized by industry. For example, a spokesperson for Drax claimed that the model was 'not a very accurate way of estimating carbon changes in forests and its scenarios were "hypothetical"'.[80] In 2015 the Department of Energy and Climate Change commissioned a further study, including an assessment of the likelihood of the high-emission scenarios, an analysis of the factors determining harvest rates as well as consideration of whether harvest rotation lengths had changed in response to the demand for biomass, whether UK demand for biomass could divert pulpwood, thinnings or sawmill residues from other users, and whether whole trees were used in pellet manufacture and if so, the carbon stock impacts.[81] At the time of publication the report is still awaited.

The evidence suggests that mature trees continue to absorb carbon (at least in old-growth forests) and that harvesting not only removes mature trees, thus substantially reducing total carbon uptake, but in the short term also increases carbon losses from soil disturbance.

The concepts of carbon debt and carbon payback have proved helpful in focusing attention on the range of factors that influence their magnitudes, and therefore the impact of different types of biomass feedstock on the climate. The approach is not, however, without its problems. It depends partly on the hypothesis that the higher levels of carbon emitted from burning woody biomass are compensated over time by faster growth of the forest from which it is sourced. This implictly accepts the argument that mature forests do not absorb carbon, and that harvesting and replacing old (carbon-neutral) trees with young (carbon-absorbing) trees increases the rate of carbon uptake in the forest, thereby offsetting the biomass-related emissions.

This is an essential part of the approach: if carbon absorption carries on at the same (or a lower) rate after harvesting as before, the carbon debt cannot be repaid. As discussed above, however, the evidence suggests that mature trees continue to absorb carbon (at least in old-growth forests) and that harvesting not only removes mature trees, thus substantially reducing total carbon uptake, but in the short term also increases carbon losses from soil disturbance. If this is correct, harvesting biomass for energy permanently reduces the rate of carbon uptake: the carbon debt can never be paid back

[79] Stephenson, A. and Mackay, D. (2014), *Life Cycle Impacts of Biomass Electricity in 2020: Scenarios for Assessing the Greenhouse Gas Impacts and Energy Input Requirements of Using North American Woody Biomass for Electricity Generation in the UK,* London: Department of Energy and Climate Change, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/349024/BEAC_Report_290814.pdf (accessed 27 Dec. 2016).
[80] Quoted in Evans, S. (2015), 'Investigation: Does the UK's biomass burning help solve climate change?'.
[81] Ibid.

and the carbon payback period is infinite. At the very least, if forest carbon uptake eventually stops (after perhaps 800 years, according to one of the studies cited above), the carbon payback period is extremely long. This may not be the case in plantations, where carbon absorption does appear to plateau, but the disturbance caused by harvesting, plus the fact the young trees absorb far less carbon than older trees, suggest long payback periods even there.

The carbon payback period and climate targets

Despite these reservations, the carbon payback approach has gained relatively wide acceptance (including in the impact assessment published by the European Commission to accompany the new draft Renewable Energy Directive in November 2016 – see further in Chapter 3). So how much does the length of the carbon payback period matter? Payback periods in the hundreds of years will counteract efforts to limit climate change over any reasonable timeframe, but what is a suitable time horizon over which to measure the impact?

Opinions on this question vary. One study considers 2050 to be an appropriate reference point, since energy systems (fossil and bioenergy) have lifetimes of typically 20 to 30 years. Of the scenarios it surveyed, only the use of residues that would otherwise have been burnt as waste or left to decay, replacing coal or oil-fired electricity (not gas), had payback period ranges falling wholly before 2050. Some of the roundwood scenarios would fall before 2050 only at the bottom end of their estimated payback ranges.

Some analysts prefer longer time horizons. A 2016 study looking at Swedish forests chose a 100-year time horizon, mirroring the Swedish Forests Agency's 100-year forest impact assessments.[82]

Other studies prefer not to specify any particular timeframe. A 2014 one drew attention to the IPCC's conclusion that it is cumulative greenhouse gas emissions that matter, not the timeframe within which these emissions are released: 'The concept of cumulative carbon also implies that higher initial emissions can be compensated by a faster decline in emissions later or by negative emissions.'[83] For carbon dioxide, the longest-lived of the greenhouse gases, it was cumulative emissions over the entire century that 'to a first approximation determine the CO_2 concentration at the end of the century, and therefore no individual year's emissions are critical'.[84] The study concluded that it is more important, therefore, to avoid lock-in of high-carbon technologies and infrastructure – such as coal – than to worry about short-term or even medium-term increases in carbon emissions, particularly if there could later be a carbon dividend from the use of biomass energy.

There are two main reasons, however, for thinking that short-term increases in carbon emissions matter. First, there is increasing concern over the possible existence of 'climate tipping points', when global temperature rise triggers a possibly irreversible change in the global climate from one stable state to another at a higher temperature. Examples include boreal forest dieback, Amazon rainforest dieback, the loss of Arctic and Antarctic sea ice and the melting of the Greenland and Antarctic ice sheets, disruption to the Indian and West African monsoon, and the loss of permafrost leading to potential Arctic methane release.[85] Although in 2013 the IPCC concluded that there was as yet

[82] Gustavsson, L. et al. (2017), 'Climate change effects of forestry and substitution of carbon-intensive materials and fossil fuels', *Renewable & Sustainable Energy Reviews*, 67, http://dx.doi.org/10.1016/j.rser.2016.09.056 (accessed 27 Dec. 2016).
[83] Miner, R. A. et al. (2014), 'Forest Carbon Accounting Considerations in US Bioenergy Policy'.
[84] Ibid.
[85] See, for example, Lenton, T. M. et al. (2008), 'Tipping Points in the Earth's Climate System', *Proceedings of the National Academy of Science*, 105:6, DOI: 10.1073/pnas.0705414105 (accessed 27 Dec. 2016).

no evidence for global-scale tipping points (though there was possibly evidence for regional-scale tipping points, particularly in the Arctic),[86] more recent studies have contested this, concluding that the probability is much higher than previously thought.[87] If this is true, the risks of increasing carbon emissions in the short or medium term are accordingly higher than considered by the IPCC in 2013.

The second reason is the global climate targets adopted at the Paris climate conference in 2015, which committed signatory countries to hold 'the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels'.[88] The IPCC is scheduled to produce a special report on the implications of the 1.5°C target in 2018, but preliminary analyses suggest that achieving this target may require emissions levels to peak very soon, perhaps as early as 2020, and then fall – though there is still considerable uncertainty over this, and longer timescales for peaking emissions have also been suggested.[89] Achieving the 1.5°C target is therefore likely to limit the use of biomass for energy to the shortest carbon payback periods.

Bioenergy with carbon capture and storage

Bioenergy with carbon capture and storage (BECCS) is a technology – as yet unproven – in which the carbon emissions from the burning of biomass for energy are captured before release into the atmosphere and permanently stored, thus removing them from the atmosphere and preventing their contribution to global warming. If it is assumed that biomass energy is carbon-neutral, BECCS generates negative carbon emissions.

The concept of BECCS emerged in the late 1990s and early 2000s.[90] In 2007, the IPCC identified BECCS as a potential option for stabilizing emissions or as a rapid-response prevention strategy for abrupt climate change. It cautioned, however, that:

> To date, detailed analysis of large-scale biomass conversion with CO_2 capture and storage is scarce… further research is necessary to characterise biomass's long-term mitigation potential… and opportunity costs… In particular, present studies are relatively poor in representing land competition with food supply and timber production, which has a significant influence on the economic potential of bio-energy crops.[91]

In 2011 a study published by the IEA reviewed the potential of BECCS in different forms, including dedicated biomass stations with CCS, co-firing with coal with CCS and liquid biofuel production with CCS.[92] It concluded that the technical potential existed for negative greenhouse gas emissions of up to 10 $GtCO_2$-eq annually (in comparison, total global emissions in 2012 were about 43 $GtCO_2$-eq), the

[86] Miner, R. A. et al. (2014), 'Forest Carbon Accounting Considerations in US Bioenergy Policy'.
[87] See, for example, Drijfhout, S. et al. (2015), 'Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models', *Proceedings of the National Academy of Science*, 112:43, DOI: 10.1073/pnas.1511451112 (accessed 27 Dec. 2016); Cai, Y., Lenton, T. M. and Lontzek, T. S. (2016), 'Risk of multiple interacting tipping points should encourage rapid CO_2 emission reduction', *Nature Climate Change*, 6, DOI:10.1038/nclimate2964 (accessed 27 Dec. 2016).
[88] Paris Agreement, Article 2 (1) (a), https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf.
[89] See, for example, Carbon Brief (2016), 'Analysis: Only five years left before 1.5C carbon budget is blown', 19 May 2016, https://www.carbonbrief.org/analysis-only-five-years-left-before-one-point-five-c-budget-is-blown (accessed 27 Dec. 2016); Hare, B. (2016), 'No time to lose: the 1.5°C limit in the Paris Agreement', Berlin: Climate Analytics, 10 August 2016, http://climateanalytics.org/blog/2016/the-1-5c-limit-in-the-paris-agreement-why-there-is-no-time-to-lose.html (accessed 27 Dec. 2016); Carbon Brief (2016), 'Highlights: Day two at the 1.5C conference on climate change in Oxford' 22 September 2016, https://www.carbonbrief.org/day-two-at-the-1-5-c-conference-on-climate-change-in-oxford (accessed 27 Dec. 2016).
[90] See Hickman, L. (2016), 'Timeline: How BECCS became climate change's "saviour" technology', Carbon Brief, 13 April 2016, https://www.carbonbrief.org/beccs-the-story-of-climate-changes-saviour-technology (accessed 28 Dec. 2016).
[91] IPCC (2007), *Climate Change 2007: Mitigation of Climate Change,* Cambridge: Cambridge University Press, p. 211, https://www.ipcc.ch/pdf/assessment-report/ar4/wg3/ar4_wg3_full_report.pdf (accessed 28 Dec. 2016).
[92] Ecofys (2011), *Potential for Biomass and Carbon Dioxide Capture and Storage,* Paris: International Energy Agency, http://www.eenews.net/assets/2011/08/04/document_cw_01.pdf (accessed 28 Dec. 2016).

largest reductions coming from dedicated biomass power generation with CCS. The report identified the immaturity of the technology, uncertainty over the availability of sustainable biomass supply and secure and permanent carbon dioxide storage, and negative public perceptions (local opposition to CCS projects) as important barriers, though it considered that the association of CCS with biomass, as a renewable energy technology, could help overcome public resistance.

In 2014 the IPCC was more positive about the potential for BECCS than in its previous assessment report. Of the 116 scenarios it reviewed aiming to achieve stabilization of carbon at 430–480 parts per million (the level considered necessary to limit global warming to 2°C), 101 involved some form of negative emissions – either through BECCS or afforestation. Every scenario aiming to limit global warming to 1.5°C included BECCS.[93] The IPCC viewed BECCS as necessary in particular to compensate for residual emissions from sectors where mitigation was more expensive, or to return to the target emissions level after an overshoot. The synthesis report concluded that: 'Many models could not limit *likely* warming to below 2°C if bioenergy, CCS, and their combination (BECCS) are limited (*high confidence*).'[94] Similarly, the full mitigation report observed that 'CDR [carbon dioxide removal] technologies such as BECCS are fundamental to many scenarios that achieve low-CO_2-eq concentrations, particularly those based on substantial overshoot as might occur if near-term mitigation is delayed'.[95]

Overall, models reported by the IPCC estimated that the global technical potential for BECCS varied from three to more than 10 $GtCO_2$/year, while cost estimates ranged from around $60 to $250/tonne CO_2. Important limiting factors included land availability, a sustainable supply of biomass and storage capacity, and possible competition for biomass from other uses of bioenergy. The IPCC cautioned that:

> The potential role of BECCS will be influenced by the sustainable supply of large-scale biomass feedstock and feasibility of capture, transport, and long-term underground storage of CO_2 as well as the perceptions of these issues. The use of BECCS faces large challenges in financing, and currently no such plants have been built and tested at scale.[96]

As of the autumn of 2016, only one commercial BECCS project was under way: Archer Daniels Midland's corn ethanol plant in Decatur, Illinois, in the US.[97] During its pilot phase in 2011–14 the plant sequestered one million tonnes of carbon dioxide from fermenting corn, which was injected into local porous sandstone formations lying beneath three layers of dense shale. With US government funding, the next phase (which was due to start in late 2016) aims to capture and store 2.26 million tonnes over two and half years. However, given the emissions produced from the energy needed to run the plant as well as to capture and store the carbon emissions, plus the carbon emitted when the ethanol itself is burnt, it is not clear whether the plant has in fact produced negative emissions. In addition, one of the aims of the project is to use some of the captured carbon dioxide for enhanced oil recovery, increasing the financial returns but further contributing to greenhouse gas emissions. Abengoa's ethanol plant in Rotterdam in the Netherlands has been capturing carbon dioxide since 2011 (about 100,000 tonnes a year), but this is used in nearby greenhouses rather than stored.[98]

[93] IPCC (2014), *Climate Change 2014: Mitigation of Climate Change.* Also see Fuss, S. (2016), 'The role of BECCS in climate change mitigation: potentials and limits', presentation to IEA BECCS Specialist Meeting, London, 23 June 2016.
[94] IPCC (2015), *Climate Change 2014: Synthesis Report,* Geneva: IPCC, p. 97, https://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_FINAL_full_wcover.pdf (accessed 28 Dec. 2016).
[95] IPCC (2014), *Climate Change 2014: Mitigation of Climate Change,* Cambridge: Cambridge University Press, p. 480.
[96] Ibid., pp. 485–86.
[97] See Carbon Brief (2016), 'Analysis: Negative emissions tested at world's first major BECCS facility', 31 May 2016, https://www.carbonbrief.org/analysis-negative-emissions-tested-worlds-first-major-beccs-facility (accessed 28 Dec. 2016).
[98] Kemper, J. (2016), 'Status of biomass with carbon capture and storage (BECCS/Bio-CCS)', presentation to IEA BECCS Specialist Meeting, London, 23 June 2016.

Overall, there are three main problems with the vision of BECCS as a major contributor to negative emissions.

First, as discussed above, the burning of biomass is not necessarily carbon-neutral at the point of combustion or even over the short or medium term – although, as discussed, it may be over the longer term depending on the carbon payback period. The surveys and models of the potential for BECCS, including those reviewed by the IPCC, simply assume that all bioenergy is carbon-neutral (provided that basic sustainability standards are in place, e.g. no conversion of forests to bioenergy crops). A 2015 survey was unable to find a single study that had calculated the potential for negative emissions based on any type of life-cycle greenhouse gas assessment that could have taken into account changes in the forest carbon stock as a result of harvesting for bioenergy.[99] The IPCC in 2014 acknowledged the potential for significant emissions from land-use change and increased nitrous oxide emissions from greater fertilizer use, but did not consider any of the wider factors discussed above.[100] In reality, since BECCS assumes that forests are planted specifically for use as energy, carbon payback periods are likely to be at the higher end of those discussed above, though it can be assumed that much of the new forest would be fast-growing softwood plantations, for which the carbon payback period is rather lower (depending partly on what the forest replaced).

The technology has proved more expensive and less effective than originally expected and, as in other areas, the falling prices of renewable energy technologies, particularly solar PV and wind, have undercut the appeal of CCS as a low-carbon option and accelerated the complete phase-out of coal.

Second, CCS technology is proving more difficult to commercialize and deploy than originally predicted. By the spring of 2016, there were 15 large-scale CCS projects in operation worldwide, capturing 28 million tonnes of carbon dioxide a year. By the end of 2017, this was projected to increase to 22 projects capturing about 40 million tonnes a year.[101] While significant, this is far off the trajectory needed to satisfy the IEA's 2015 prediction that CCS would capture two billion tonnes a year by 2030. Furthermore, most of the projects currently operating are producing carbon dioxide for enhanced oil recovery rather than permanent storage. In general, the technology has proved more expensive and less effective than originally expected and, as in other areas, the falling prices of renewable energy technologies, particularly solar PV and wind, have undercut the appeal of CCS as a low-carbon option and accelerated the complete phase-out of coal, thus removing one of the sources of fossil fuels CCS was intended to operate alongside. CCS equipment can be fitted to gas-fired power plants and industrial processes, but the benefits in terms of reducing carbon emissions are lower, and therefore the cost per tonne of carbon captured is higher. Further technological development can be expected, but it is difficult not to conclude that the current speed of development and deployment of CCS is too low to justify the reliance placed on BECCS by the IPCC.

Third, as noted by the IPCC and others, the availability of land for bioenergy is a limiting factor. The highest estimates of BECCS assume that 15–18 $GtCO_2$ could be removed per year, with energy production of 200–400 EJ per year. This comprises 80–100 EJ/year from the by-products of

[99] Ernsting, A. and Munnion, O. (2015), *Last-ditch Climate Option or Wishful Thinking? Bioenergy with carbon capture and storage,* Biofuelwatch, http://www.biofuelwatch.org.uk/wp-content/uploads/BECCS-report-web.pdf [Accessed 28 Dec. 2016).
[100] IPCC (2014), *Climate Change 2014.*
[101] Global CCS Institute (undated), 'Large Scale CCS Projects', http://www.globalccsinstitute.com/projects/large-scale-ccs-projects.

agriculture and forest industries, and the remaining 180–300 EJ/year from dedicated energy crops.[102] (These are very large quantities; in comparison, world energy production was roughly 575 EJ in total in 2014.)[103] A review in 2015 calculated that production of 100 EJ/year could require up to 500 million hectares of land (assuming an average biomass yield of 10 tonnes of dry biomass per hectare annually). The top end of the projections for BECCS would therefore require two billion hectares – an area greater than the total global land area currently planted with agricultural crops (about 1.5 billion hectares in 2015) and about half the total global forest area (about 4 billion hectares).[104] Scenarios like this also tend to assume radical changes in behaviour, including a major shift away from eating meat (releasing much of the land currently used for pasture, about 3.4 billion hectares), together with rapid increases in food yields (sufficient to meet global food demand, which is projected to double over the next 50 years). Neither of these developments seems at all likely.

Another study that focused on using switchgrass for feedstock estimated that 200 million hectares (about half the total cropland of the US) would be needed to remove 3.7 $GtCO_2$ per year (about one-fifth of the volume estimated in the highest projections for BECCS).[105] The process would also consume 20 per cent of global fertilizer production and require 4,000 km^3/year of water, equal to current global water withdrawals for irrigation.

For all these reasons, the prospects for the development of BECCS at scale seem highly unlikely; and, in any case, its impacts on the climate would not necessarily be positive in the short term. The reliance on BECCS of so many of the climate-mitigation scenarios reviewed by the IPCC is of major concern, potentially distracting attention from other mitigation options and encouraging decision-makers to lock themselves into high-carbon options in the short term on the assumption that the emissions thus generated can be compensated for in the long term.[106]

Conclusions and recommendations

Changes in the forest carbon stock must be fully accounted for in assessing the climate impact of the use of woody biomass for energy. It is not valid to claim that because trees absorb carbon as they grow, the emissions from burning them can be ignored. This is true whether or not the forest from which the biomass is sourced is sustainably managed, or whether it is growing in size, or whether forests as a whole are expanding. All these approaches either treat what happens to the trees after they are harvested as irrelevant, or ignore the carbon sequestration forgone when the trees are harvested, or both. As the European Commission Joint Research Centre concluded:

> in order to assess the climate change mitigation potential of forest bioenergy pathways, the assumption of biogenic carbon neutrality is not valid under policy relevant time horizons (in particular for dedicated harvest of stemwood for bioenergy only) if carbon stock changes in the forest are not accounted for.[107]

[102] US National Research Council (2015), *Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration,* p. 54, Washington, DC: National Academies Press, http://dels.nas.edu/resources/static-assets/materials-based-on-reports/reports-in-brief/climate-intervention-brief-final.pdf (accessed 28 Dec. 2016).
[103] IEA (2016), *Key World Energy Trends 2016,* Paris: IEA, https://www.iea.org/publications/freepublications/publication/KeyWorldEnergyTrends.pdf (accessed 28 Dec. 2016).
[104] Food and Agriculture Organization United Nations (FAO) (2016), *State of the World's Forests 2016, Forests and agriculture: land-use challenges and opportunities,* Rome: FAO, http://www.fao.org/3/a-i5588e.pdf (accessed 28 Dec. 2016).
[105] Reviewed in US National Research Council (2015), *Climate Intervention.*
[106] See also Anderson, K. and Peters, G. (2016), 'The trouble with negative emissions', *Science,* 14 October 2016, DOI: 10.1126/science.aah4567 (accessed 28 Dec. 2016).
[107] Agostini, A., Giuntoli, J. and Boulamanti, A. (2013), *Carbon accounting of forest bioenergy*, p. 77.

Along with changes in forest carbon stock, a full analysis of the impact on the climate of using woody biomass for energy needs to take into account the emissions from combustion (which are generally higher than those for fossil fuels) and the supply-chain emissions from harvesting, collection, processing and transport. There is still some uncertainty over some of these factors, including levels of supply-chain emissions, the impact on soil carbon and tree growth of using forest residues, and levels of methane emissions produced during the storage of wood pellets and wood chips. The rate of carbon absorption by mature trees is routinely ignored by many of the models used to predict climate impacts. More research into all these issues would be helpful.

There is also uncertainty over market dynamics. While it may be the case that the growth of the woody biomass industry could lead to greater investment in forests, and therefore a higher rate of tree planting, which can help to offset higher emissions from combustion, the evidence for this happening is so far largely lacking. In any case, the models that predict this often assume that old-growth forests are replaced by fast-growing plantations, which in itself leads to higher carbon emissions, together with negative impacts on biodiversity.

Notwithstanding all this, harvesting of whole trees for energy will in almost all circumstances increase net carbon emissions very substantially compared to using fossil fuels, because of the loss of future carbon sequestration from the growing trees and because of the loss of soil carbon consequent upon the disturbance. This is particularly true for mature trees in old-growth forests, whose rate of carbon absorption can be very high.

The use of sawmill residues for energy has lower impacts, because it involves no additional harvesting as it is waste from other wood industry operations. The impact will be most positive for the climate if they are burnt on-site for energy without any associated transport or processing emissions. However, mill residues can also be used for wood products such as particleboard; if diverted instead to energy, this will raise carbon concentrations in the atmosphere. The current high levels of use of mill residues mean that this source is unlikely to provide much additional feedstock for the biomass energy industry in the future (or, if it does, it will be at the expense of other wood-based industries). Black liquor, a waste from the pulp and paper industry, can also be burnt on-site for energy and has no other use; in many ways it is the ideal feedstock for biomass energy.

The use of forest residues for energy also implies no additional harvesting, so its impacts on net carbon emissions can be low. This depends mainly on the rate at which the residues would decay and release carbon if left in the forest, which can vary substantially. If slow-decaying residues are burnt, the impact would be an increase in net carbon emissions, potentially for decades. In addition, removing residues from the forest can adversely affect soil carbon and nutrient levels as well as tree growth rates.

The carbon payback approach argues that, while they are higher than using fossil fuels, carbon emissions from burning woody biomass can be absorbed by forest regrowth. The time this takes – the carbon payback period before which carbon emissions return to the level they would have been at if fossil fuels had been used – is of crucial importance. There are problems with this approach, but it does help to highlight the range of factors that affect the impact of biomass, and focuses attention on the very long payback periods of some feedstocks, particularly whole trees, which is a matter of considerable concern given the potential existence of climate tipping points and the near-term targets for carbon emission reductions agreed in Paris in 2015.

For all these reasons, the provision of financial or regulatory support to biomass energy on the grounds of its contribution to mitigating climate change needs to be strictly controlled. Only

those feedstocks that reduce carbon emissions over the short term should be eligible. This topic is considered further in Chapter 3.

Finally, while interest is growing in BECCS, its future development at scale seems highly unlikely, given the slow rate of commercialization of CCS technology and likely limits on the availability of land. In addition, the studies of options for BECCS almost always assume that biomass is zero-carbon at the point of combustion – which, as argued above, is not a valid assumption. The reliance on BECCS of so many of the climate-mitigation scenarios reviewed by the IPCC is, accordingly, of major concern, potentially distracting attention from other mitigation options and encouraging decision-makers to lock themselves into high-carbon options in the short term on the assumption that the emissions thus generated can be compensated for in the long term.

2. Accounting for Biomass Carbon Emissions

This chapter examines the way in which biomass is treated as carbon-neutral at the point of combustion because it is assumed that its emissions are accounted for in the land-use sector, and not in the energy sector, under international rules for greenhouse gas emissions. The following issues are discussed:

- Reporting and accounting rules for biomass under the UNFCCC and Kyoto Protocol, and the impact of parties' choice of forest-management reference levels.
- An analysis of the different ways in which biomass energy emissions can go unaccounted for, or 'missing'.
- A summary of the forest-management reference levels adopted by Annex I parties to the UNFCCC, and the levels of emissions from the use of solid biomass for energy.
- National case studies of the UK, the US, Finland and France, identifying where biomass emissions may go unaccounted for.

Reporting and accounting

This treatment is essentially an artefact of the approach taken by the Intergovernmental Panel on Climate Change (IPCC) to greenhouse gas reporting and accounting. Greenhouse gas *reporting* under the UN Framework Convention on Climate Change (UNFCCC) is the process of estimating and compiling national emissions data in order to describe the amounts of, and trends in, countries' emissions. *Accounting*, by contrast, involves applying a set of predetermined rules and conventions to reported data so as to assess countries' progress towards their national emissions targets under the Kyoto Protocol (or any other climate regime with targets).[108] While reporting is a necessary precursor to accounting under the UNFCCC, the two processes are distinct. Not all emissions included in a country's greenhouse gas *reports* will necessarily be reflected in its greenhouse gas *accounts*.

In principle the changes in carbon emissions resulting from the harvesting of woody biomass and its burning for energy could be reported in either the land-use sector, at the point of harvesting and removal from the forest, or in the energy sector, at the point of combustion. In order to ensure consistency and avoid double-counting, the IPCC determined that countries should report emissions from biomass combustion only in their land-use sectors. It is this categorization of emissions that has led many policymakers to perceive biomass as a carbon-neutral energy source (although this was not the IPCC's intention).

The IPCC's approach is logical in the context of greenhouse gas *reporting*, for which countries estimate and report emissions from all sectors. However, problems start to arise when countries *account* for changes in their greenhouse gas emissions against their national targets under the Kyoto Protocol. Accounting for emissions from the land-use sector has always been a complex issue as,

[108] Canaveira, P. (2014), *Options and Elements for an Accounting Framework for the Land Sector in the Post-2020 Climate Regime*, Lisbon: Terraprima, www.terraprima.pt/pt/file_download/172 (accessed 28 Dec. 2016).

unlike other ones, this sector is subject to significant natural variation in emissions levels as a result of climatic impacts on growth as well as of fires, insect infestations and diseases. There has been considerable debate over how to account for the associated emissions, leading to specific sets of rules for land use, land-use change and forestry, which have been applied at a different pace than the rules for emissions accounting in other sectors. Problems can arise when a country does not account for land-use sector emissions at all, or accounts for them only incompletely, or accounts for its land-use and energy sectors using different benchmarks.

Accounting in the Kyoto Protocol's first commitment period

In the first commitment period of the Kyoto Protocol (2008–12), UNFCCC Annex I parties (essentially, developed countries) could choose whether or not to account at all for emissions from forest-management activities.[109] Of the 38 parties to the protocol, 24 chose to include forest-management emissions; the land-use sector accounts of those 24 parties therefore at least partially reflected changes in emissions attributable to the use of forest biomass for energy. Emissions associated with forest-based bioenergy were not reflected anywhere in the accounts of the other 14 parties.

It is possible, however, to calculate the total volume of biomass-related emissions, as under the UNFCCC, Annex I countries are requested to report carbon dioxide emissions from biomass used for energy as a separate line item (referred to as a 'memo item') in their greenhouse gas inventories. As noted, these are not included in the total reported emissions for the energy sector, as it is assumed they are reflected in the land-use emissions inventory.[110] Over the five years of the first commitment period, carbon dioxide emissions from biomass energy use in Annex I countries totalled approximately 4.16 Gt. This figure includes emissions from solid, liquid and gaseous biomass used for energy in all sectors of the economy – solid biomass includes wood and wood waste, black liquor, other primary solid biomass (such as municipal solid waste) and charcoal. The proportion of total biomass energy emissions attributable to solid biomass varied widely between countries, from 0 per cent to 100 per cent; on average it comprised approximately 78 per cent of all biomass energy emissions in 2012.

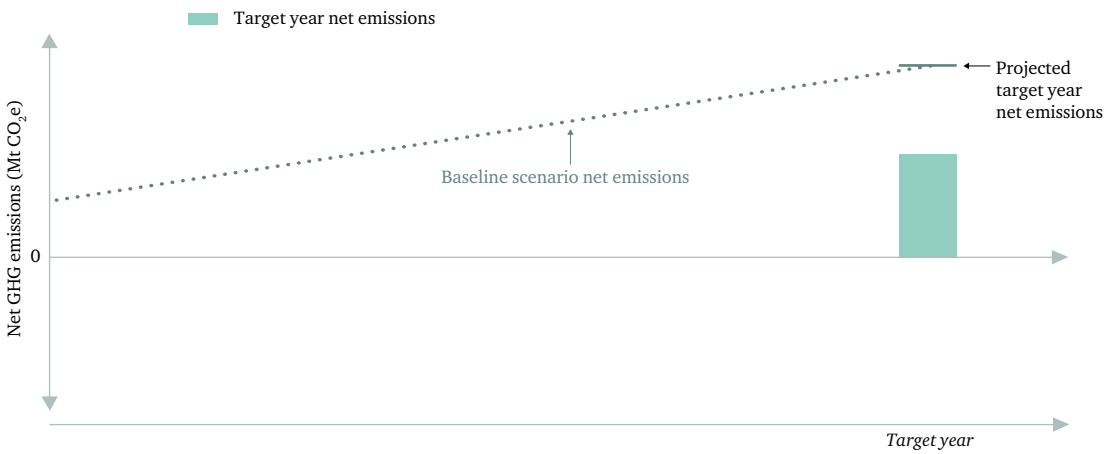
Accounting in the Kyoto Protocol's second commitment period

For the Kyoto Protocol's second commitment period (2013–20), parties agreed to adopt mandatory accounting of emissions from forest management. Parties were permitted to choose the reference level of emissions against which they accounted for changes, subject to agreed parameters and processes. This is different from how changes in emissions in the energy and other sectors are assessed, which is against a historical baseline of emissions in 1990. Of the 37 parties that adopted targets for the protocol's second commitment period, 32 chose to account for changes in forest-management emissions against a business-as-usual baseline and three chose a historical baseline; the other two did not submit a forest-management reference level.

[109] This analysis focuses on Annex I countries, countries the UNFCCC classifies as 'developed', because: (1) these countries are more likely to have in place national policies encouraging the use of biomass for energy, and (2) these countries are required to submit annual greenhouse gas inventories including information on emissions from biomass energy.
[110] Non-CO_2 greenhouse gas emissions from burning biomass (e.g. methane) for energy *are* reported in the energy sector, as they do not exist in the land-use sector.

A business-as-usual baseline is expressed as average annual forest-management emissions projected over the second commitment period (see Figure 3).

Figure 3: Business-as-usual accounting in the land-use sector



Source: World Resources Institute (2014), *Greenhouse Gas Protocol Mitigation Goal Standard: An accounting and reporting standard for national and subnational greenhouse gas reduction goals,* p. 82, https://www.wri.org/sites/default/files/Mitigation_Goal_Standard.pdf.

Parties choosing a business-as-usual baseline generally did so in order to minimize the potential for non-anthropogenic and/or non-additional emissions entering their national greenhouse gas accounts. However, in practice, using this baseline also allows a country to avoid accounting for a portion of emissions from biomass energy use (and other forest-management practices).

A business-as-usual baseline accounts for forest management relative to a *projection* – a prediction of net emissions over the commitment period. This projection may include anticipated levels of harvesting of forest biomass for energy. If so, the associated emissions will not count towards the country's emissions target since they are already included in the baseline. (This is as long as the emissions are in line with the projection; if they are higher, then the difference between actual and projected emissions will be counted.) Only where a country does *not* include anticipated emissions from biomass energy in its business-as-usual baseline will it count *all* such emissions against its target.

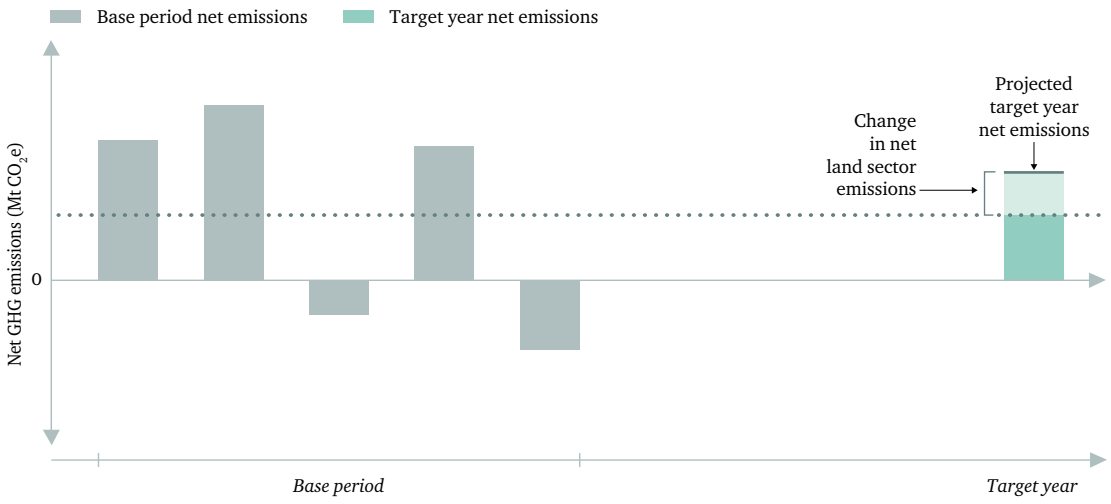
This explanation assumes that all other emissions included in a business-as-usual reference level occur as projected. Accounting in the land-use sector does not differentiate between sources of emissions – for example, between emissions from forest biomass harvested for energy and emissions from harvests for wood pulp. It is therefore possible that increases in emissions from biomass energy could be balanced by falls in emissions from other activities. In this situation, a country would be able to register zero emissions in its account even though emissions from forest-based biomass energy were higher than predicted. The analysis below assumes that all non-bioenergy emissions occur as predicted in the business-as-usual projection, in order to highlight the impacts of forest-based biomass energy use on accounting.

The forest-management guidance for the Kyoto Protocol's second commitment period specifies that countries should not include the effects of policies adopted and implemented after 31 December 2009 in their reference levels. Thus, countries using business-as-usual baselines *will* count emissions attributable to post-2009 policies, including those promoting the use of forest-based bioenergy, against their emissions targets. Parties must also account for the effects of any changes to pre-2010

policies implemented after 2009. Policies adopted and implemented prior to 2010 may be included in the reference level, though EU member states have agreed not to include policies stemming from the implementation of the 2009 EU Renewable Energy Directive.

Countries choosing to use a historical baseline, rather than a business-as-usual one, account against their forest-management emissions in 1990 (in line with accounting for other sectors) or their average annual emissions over a historical period, e.g. 1990–2009 (see Figure 4). Parties may have opted to use a historical baseline to maintain continuity with past accounting practices or to maintain consistency with accounting in other sectors. Emissions levels from a historical baseline are also easier to determine. Depending on the circumstances, the level of historical emissions may in fact be the most accurate predictor of future emissions.

Figure 4: Historical base year/base period accounting in the land-use sector



Source: World Resources Institute (2014), *Greenhouse Gas Protocol Mitigation Goal Standard: An accounting and reporting standard for national and subnational greenhouse gas reduction goals, p. 81,* https://www.wri.org/sites/default/files/Mitigation_Goal_Standard.pdf.

Even accounting relative to a historical base year does not result in 'complete' carbon accounting since the quantity of emissions occurring in the base year is subtracted from emissions in the commitment period: it is only the *change* in emissions that appears in the country's greenhouse gas accounts. The full quantity of emissions appears only in a country's greenhouse gas inventory *reports*. However, using the same historical benchmark for the energy and land-use sectors at least puts emissions from forest biomass-based energy on the same footing as emissions from other energy sources, thus minimizing the potential for leakage between the sectors. When the accounting system values a tonne of emissions from biomass energy the same as it values a tonne of emissions generated from other energy sources, it is less likely that mitigation targets in the energy sector will drive perverse outcomes.

Countries without sufficient domestic resources to satisfy their biomass energy demand may import woody biomass for use in their energy sectors. Because the IPCC guidance provides that emissions from biomass energy are not accounted for within the energy sector, emissions from combusting imported biomass for energy are automatically precluded from appearing anywhere in an importing country's accounts. Whether the associated emissions are accounted for in the country of origin depends on whether the exporting country accounts for forest-management emissions, and, if so, what kind of reference level it uses.

The potential for 'missing' biomass energy emissions

The accounting framework described earlier creates the potential for biomass energy emissions to go unaccounted for, or 'missing', in three possible ways.

Imported forest biomass used for energy

The first and most obvious cause of unaccounted-for emissions is due to biomass imported from non-accounting countries. As noted, it is the exporting countries that should account for the carbon emissions, but this will not hold true when the countries growing and harvesting the biomass fall outside the accounting framework. This is the case for the US, Canada and Russia, all significant exporters of woody biomass that do not account for greenhouse gas emissions under the second commitment period of the Kyoto Protocol (though their emissions will be *reported* – as opposed to accounted for – under the UNFCCC).

Imports of forest biomass from countries that *do* account for greenhouse gas emissions within the land-use sector may also result in missing carbon emissions, depending on the exporting country's reference-level approach.

Historical reference levels

A historical reference level reflecting past emissions that are higher than current levels will allow a country to increase its emissions over the commitment period up to that historical level without accounting for the increase. In fact, if a country remains below its historical emissions level it will receive credits – commonly referred to as 'hot air', or non-additional greenhouse gas reductions. In contrast, a country with a historical reference level reflecting a lower level of emissions than ultimately occur in the commitment period will account for emissions above the historical level.

Although a historical reference level that allows for unaccounted increases in emissions may result in 'missing' biomass energy emissions, this phenomenon is no different from greenhouse gas accounting in any other sector under the Kyoto Protocol. If the same historical year or period is used for the reference level in the land-use and energy sectors, and if the sectors are fungible, emissions from biomass energy are on an equal footing with emissions from other energy sources. In this case, the potential for leakage between sectors is minimized, also reducing the potential for biomass energy policies to drive perverse outcomes.

Business-as-usual (projected) reference levels

If a country's projected reference level includes policies aimed at increasing the use of forest biomass for energy, it will not account for the emissions resulting from those policies (as long as they were adopted before 2010) against its greenhouse gas targets. An accounting framework that allows countries to build anticipated increases in forest harvests into their projections thus fails to reflect the true atmospheric impacts of forest-based biomass energy.

If its projected reference level does *not* include the impacts of bioenergy policies, a country will count emissions attributable to those policies against its allowable target level of emissions. However, even countries that have not explicitly included anticipated emissions increases due to bioenergy policies in their reference levels have often implicitly built some amount of bioenergy use into their business-as-usual projections. The resulting emissions will not count towards their emissions targets.

Harvested wood products

In addition, for countries using business-as-usual reference levels, accounting for emissions from harvested wood products may help to bring some emissions from forest-based biomass energy back into the accounting framework. The rules for harvested wood products were amended in the second commitment period to allow countries to assume that forest carbon can be stored in long-lived products. Under these rules, countries account for emissions from harvested wood products according to a set of first-order decay functions and default half-lives for three categories of products: paper (two years), wood panels (25 years), and sawnwood (35 years). (Carbon dioxide emissions from wood harvested for energy purposes are assumed to occur in the year of harvest.)[111]

Countries using business-as-usual reference levels generally allocate their future harvests to one of the four categories above – paper, wood panels, sawnwood or biomass for energy – based on their historical inputs into each product category. For example, if a country used 15 per cent of the volume of its domestic forest harvests for energy in the past, its reference level would assume that 15 per cent of the volume harvested over the commitment period would be used for energy. The emissions associated with the corresponding volume of biomass used for energy would not count against that country's target, as those emissions were included in the reference level and thus 'cancelled out' of accounting.

> Where a tonne of emissions from burning biomass for energy does not count against a country's emissions target but a tonne of emissions from fossil fuel energy sources does, there will be an incentive to use biomass energy rather than fossil fuels in order to reduce the country's greenhouse gas emissions.

Due to the differences in the timing of emissions between harvested wood products and biomass used for energy, however, a country that uses a greater proportion of its domestic harvests for energy than in the past may account for the marginal increase in emissions. Emissions from the creation of longer-lived harvested wood products – wood panels and sawnwood – do not occur in the commitment period and thus are not included in a projected reference level. However, if a country increases the proportion of harvested biomass it uses for energy and reduces its production of long-lived harvested wood products, the associated volume of carbon dioxide will now occur in the commitment period. Because the reference level did not include those emissions, a country that increases the portion of its domestic forest harvests used for energy may count the marginal increase in emissions against its emissions target.

Summary

There is a risk of carbon emissions going unaccounted for or 'missing' as long as (1) forest biomass-exporting countries remain outside the greenhouse gas accounting framework, (2) emissions in the land-use and energy sectors are accounted for using different approaches, or (3) countries build the emissions resulting from policies promoting biomass energy use into their accounting baselines.

This risks creating perverse policy outcomes. Where a tonne of emissions from burning biomass for energy does not count against a country's emissions target but a tonne of emissions from fossil fuel

[111] UNFCCC decision 2/CMP.7, Annex paras. 29–32.

energy sources does, there will be an incentive to use biomass energy rather than fossil fuels in order to reduce the country's greenhouse gas emissions – even where this reduction is not 'real' in the sense that it is not accounted for in any country's land-use sector accounts.

Biomass energy emissions in the second commitment period

There are currently 43 Annex I countries under the UNFCCC.[112] Thirty-five of them have submitted reference levels to use for forest-management accounting in the second commitment period of the Kyoto Protocol (see Table 4). The remaining eight are either not parties to the protocol (Canada, the US), are parties without targets under its second commitment period (Japan, New Zealand, Russia, Turkey) or have not so far submitted a forest-management reference level (Monaco, which has no forests, and Kazakhstan).

Three of these 35 countries submitted forest-management reference levels based on historical emissions. Two account for changes relative to 1990 levels while the third accounts for changes relative to its average forest-management emissions in 1990–2009. The greenhouse gas accounts of these three parties will include any changes in emissions attributable to the use of forest-based biomass for energy relative to these historical levels.

The other 32 parties elected to use business-as-usual reference levels for forest-management accounting for the second commitment period. Sixteen used country-specific models or methodologies to calculate their business-as-usual scenarios: 14 EU member states relied on projections modelled by the European Commission's Joint Research Centre and two parties used a linear extrapolation of historical emissions data. As discussed above, the impacts of pre-2010 biomass energy policies may be included in these parties' reference levels, with the effect that emissions attributable to those policies will not be included in their accounting.

Of the 32 parties using business-as-usual reference levels for forest management, 21 explicitly included policies encouraging the use of biomass energy within their emissions projections. The remaining 11 countries did not model the impacts of such policies within their reference levels. This does not preclude the possibility that any increases in forest harvests and/or biomass utilization included in these countries' business-as-usual projections could be used for biomass energy, but there is no causal link within the reference level between anticipated biomass energy demand and forest harvests. Consequently, any increases in emissions built into the reference level (and therefore excluded from accounting) are not directly attributable to increased demand for biomass energy.

For the 21 countries that explicitly included the impacts of biomass energy policies, some quantity of emissions over the commitment period will result from biomass energy use, but these emissions will not count against the countries' national targets since they are included in the reference level. The question then is: how large is the quantity of unaccounted-for emissions?

[112] Including Kazakhstan, which is an Annex I country for the purposes of the Kyoto Protocol though not the UNFCCC.

Table 4: Forest-management reference levels for the second commitment period of the Kyoto Protocol

	Type of reference level	Reference level includes policies driving biomass energy use?	Explanation
Australia	Country-specific projection	No	
Austria	Country-specific projection	Yes	Includes increase in demand for woody biomass for energy of 20 per cent from 2008–20; gross domestic consumption of woody biomass for energy from 18 million cubic metres (Mm^3) (145 petajoules – PJ) in 2009 to 21–22 Mm^3 (170–175 PJ) in 2020. Assumes ~20 per cent supply from imports.
Belarus	1990 (historical base year)	N/A	
Belgium	Joint Research Centre (JRC) projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Bulgaria	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Croatia	Country-specific projection	Yes	Biomass energy is a driver of increased harvests from 5.15 Mm3 in 2010 to 8.00 Mm3 in 2020, but not possible to calculate specific portion of increase due to energy policy.
Cyprus	Linear extrapolation	N/A	
Czech Republic	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Denmark	Country-specific projection	No	
Estonia	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Finland	Country-specific projection	Yes	Projection includes increased use of wood chips from 5.3 TWh in 2007 to 21 TWh in 2020, increased use of wood/wood pellets from 13.7 to 16 TWh. Black liquor, industrial wood residues, wood chips for biofuels included. Assumes increased harvesting and rate of harvesting logging residues and stumps; reduced dependence on imports.
France	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Germany	Country-specific projection	No	
Greece	1990–2009 (historical base period)	N/A	
Hungary	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Iceland	Country-specific projection	No	
Ireland	Country-specific projection	No	

	Type of reference level	Reference level includes policies driving biomass energy use?	Explanation
Italy	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Latvia	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Liechtenstein	Country-specific projection	Yes	Projection includes an increase in harvests, an unknown portion of which is attributable to increasing use of forest biomass for energy.
Lithuania	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Luxembourg	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Malta	Linear extrapolation	N/A	
Netherlands	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Norway	1990 (historical base year)	N/A	
Poland	Country-specific projection	No	
Portugal	Country-specific projection	Yes	Projected increase in harvests of 6 per cent attributable to expansion of pulp and bioenergy sectors.
Romania	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Slovakia	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Slovenia	Country-specific projection	No	
Spain	JRC projection	Yes	Projection includes demand for biomass and waste for electricity and thermal energy; cannot determine type or origin of fuel.
Sweden	Country-specific projection	Yes	Projection includes increased use of forest residues and stumps for biomass energy from 8.6 TWh in 2010 to 13.3 TWh in 2020. Area of stump harvest increases from 4,800 hectares in 2010 to 23,400 hectares in 2020.
Switzerland	Country-specific projection	Yes	Projection includes 30 per cent increase in harvesting rates in 2013–20 relative to 1990–2007, an unknown portion of which is attributable to increasing use of forest biomass for energy.
Ukraine	Country-specific projection	No	
UK	Country-specific projection	No	

The volume of 'missing' biomass energy emissions

For the most part, the information provided in countries' forest-management reference level submissions is not sufficient to answer the question above. Ideally, these submissions would have specified the anticipated impact of biomass energy policies on the quantity of woody biomass utilized, the origins of that biomass (additional domestic forest harvests, increased use of domestic forestry residues or higher imports) and the resulting emissions. However, of the 21 countries whose reference levels explicitly included biomass energy policies, only three – Austria, Finland and Sweden – quantified their impacts. Several other countries indicated that they had built anticipated increases in biomass energy use into their reference levels, but did not provide sufficient data to quantify the resulting impact.

As noted above, however, it is possible to calculate carbon dioxide emissions from biomass from the emissions reported as a memo item in Annex I countries' greenhouse gas inventory reports. This covers emissions from biomass used for energy in all sectors, including energy, manufacturing and construction, transport, commercial and institutional, residential, agriculture, forestry and fisheries.

The 2006 IPCC Guidelines for National Greenhouse Gas Inventories divides biomass used for energy into three categories: solid, liquid and gaseous.[113] Solid biomass includes wood and wood waste, sulphite lyes (black liquor), other primary solid biomass such as plant matter, vegetal waste and animal materials and wastes, and charcoal. Liquid biomass includes biogasoline, biodiesel and other liquid biofuels. Gaseous biomass covers landfill biogas, sludge biogas and other biogas. The biodegradable fraction of municipal wastes is also included in the IPCC's definition of biomass fuels, though some countries have now started to report emissions from municipal solid waste separately.

Although the memo item for carbon dioxide emissions from biomass energy does not break down emissions by the source of biomass, most countries report the type of biomass used in a separate emissions calculation based on economy-wide fuel use.[114] Table 5 applies the proportion of emissions from solid biomass in this second calculation to each country's memo item emissions to estimate the proportion of carbon dioxide emissions attributable to the combustion of solid biomass.[115] Not all countries differentiate between emissions from solid, liquid and gaseous biomass, and some include municipal solid waste while others do not. This reinforces the fact that the figures cited here are estimates rather than precise figures.

[113] IPCC (2006), *IPCC Guidelines for National Greenhouse Gas Inventories, Vol. 2: Energy,* Ch. 1: Introduction, pp. 1.15–16, http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_1_Ch1_Introduction.pdf (accessed 29 Dec. 2016).
[114] Total reported carbon dioxide emissions from biomass energy in the memo item are calculated using the IPCC's bottom-up 'sector approach'. Biomass energy emissions in the second analysis are calculated using a top-down 'reference approach'. The emissions estimates resulting from the sector and reference approaches are very rarely, if ever, equivalent; it is not possible to compare these values directly.
[115] Not all countries included this second calculation always differentiate between categories of biomass fuels in their inventories. For countries and years for which this information is not available, the portion of emissions attributable to solid biomass is based on information included in those countries' National Inventory Reports, where available.

Table 5: Carbon dioxide emissions from total biomass and solid biomass

	1990			2000			2010			2014		
	Total biomass emissions ($MtCO_2$)	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*	*Total biomass emissions ($MtCO_2$)*	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*	*Total biomass emissions ($MtCO_2$)*	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*	*Total biomass emissions ($MtCO_2$)*	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*
Australia	15.14	100	15.14	19.24	98	18.86	18.51	97	17.95	18.04	96	17.32
Austria	9.93	98	9.70	12.48	95	11.87	23.25	87	20.12	23.35	81	18.92
Belarus	2.01	45	0.91	3.04	14	0.43	5.15	29	1.49	5.10	52	2.65
Belgium	2.30	76	1.75	2.96	75	2.21	11.60	73	8.50	11.00	71	7.82
Bulgaria	0.81	100	0.81	2.58	100	2.58	4.30	14	0.60	5.06	4	0.21
Canada	49.81	59	29.27	55.81	55	30.46	51.67	57	29.60	55.10	55	30.57
Croatia	5.13	100	5.13	4.70	100	4.70	5.94	100	5.91	5.25	97	5.10
Cyprus	0.02	100	0.02	0.03	100	0.03	0.14	59	0.08	0.14	53	0.08
Czech Republic	5.42	99	5.34	5.32	90	4.78	9.94	86	8.60	13.25	78	10.34
Denmark	4.57	73	3.33	6.84	64	4.36	14.90	77	11.52	14.72	73	10.73
Estonia	0.96	100	0.96	2.30	100	2.30	3.73	99	3.67	3.77b	99	3.72
Finland	19.33	100	19.33	29.45	100	29.40	36.38	98	35.79	39.38	96	37.87
France	44.27	83	36.90	42.83	78	33.50	60.00	78	46.80	57.30	73	41.57
Germany	21.80	100	21.80	34.25	100	34.25	108.51	100	108.51	98.53	100	98.53
Greece	2.08	100	2.08	2.73	100	2.73	2.83	NO	0.00	2.68	NO	0.00
Hungary	3.13	97	3.05	3.41	95	3.25	8.03	89	7.15	7.54	87	6.59
Iceland	NA, NO	NA	NA, NO	NA, NO	NA	NA, NO	NA, NO	NA	NA, NO	NA, NO	NA	NA, NO
Ireland	0.49	99	0.49	0.59	89	0.52	1.37	60	0.83	1.91	61	1.16
Italy	13.95	98	13.70	18.67	72	13.53	41.81	70	29.24	40.59	71	28.87
Japan	34.86	100	34.86	39.62	100	39.62	57.79	100	57.79	59.99	100	59.97
Kazakhstan	1.17	100	1.17	0.34	100	0.34	0.55	100	0.55	0.31	100	0.31
Latvia	3.03	100	3.03	4.37	100	4.37	5.15	97	5.02	6.46	96	6.18

	1990			2000			2010			2014		
	Total biomass emissions ($MtCO_2$)	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*	*Total biomass emissions ($MtCO_2$)*	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*	*Total biomass emissions ($MtCO_2$)*	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*	*Total biomass emissions ($MtCO_2$)*	*% from solid biomass*	*Solid biomass emissions ($MtCO_2$)*
Liechtenstein	0.01	72	0.00	0.01	79	0.01	0.02	88	0.02	0.02	93	0.02
Lithuania	1.31	100	1.31	2.97	100	2.97	4.48	96	4.32	5.28	94	4.98
Luxembourg	0.16	NO	NO	0.15	50	0.08	0.45	44	0.20	0.57	43	0.25
Malta	IE, NO	NE	NE	IE, NO	NE	NE	0.00	NE	NE	0.02	NE	NE
Monaco	0.03	NO	NO	0.05	NO	NO	0.04	NO	NO	0.04	NO	NO
Netherlands	4.08	59	2.40	6.81	50	3.43	13.3	55	7.35	12.76	44	5.66
New Zealand	3.61	95	3.43	5.33	97	5.18	5.70	94	5.37	5.49	94	5.16
Norway	4.48	100	4.48	4.71	100	4.71	6.40	100	6.40	3.91	100	3.91
Poland	6.81	99	6.80	16.90	99	16.80	30.4	89	27.1	34.40	90	30.82
Portugal	11.40	86	9.75	11.68	78	9.12	12.90	67	8.60	11.17	60	6.67
Romania	2.76	100	2.76	12.95	100	12.95	18.96	98	18.58	17.47	97	16.89
Russia	62.57	100	62.27	18.55	98	18.15	14.85	100	14.85	13.62	100	13.62
Slovakia	1.74	99	1.72	3.15	75	2.36	5.54	80	4.45	7.85	73	5.75
Slovenia	2.18	100	2.18	1.98	100	1.98	3.16	93	2.95	2.86	93	2.65
Spain	18.23	100	18.20	16.97	95	16.17	24.82	80	19.78	26.78	82	22.00
Sweden	12.39	97	12.10	17.02	97	16.56	30.07	55	16.40	28.32	52	14.61
Switzerland	4.47	97	4.33	4.74	95	4.52	6.55	96	6.29	6.66	95	6.32
Turkey	32.82	100	32.82	29.56	100	29.56	20.87	100	20.84	15.25	98	14.98
Ukraine	1.19	100	1.19	2.66	100	2.66	3.70	100	3.70	4.82	100	4.82
UK	2.55	82	2.08	6.24	61	3.84	19.25	50	9.64	27.96	57	15.88
US	219.41	98	215.02	227.43	97	210.76	265.11	72	191.59	293.73	74	217.65
Totals	**632.41**		**591.61**	**681.42**		**605.90**	**958.12**		**768.15**	**984.68**		**781.15**

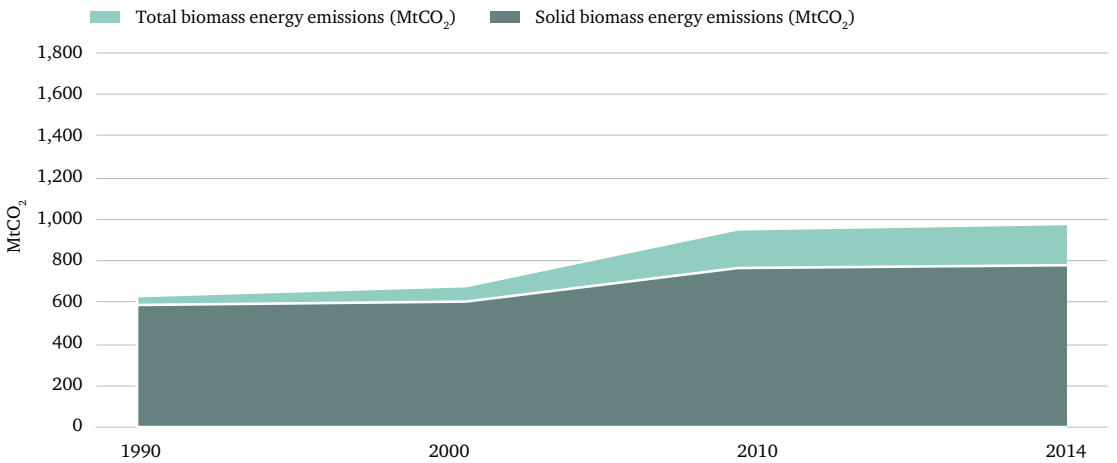
IE = included elsewhere; NA = not applicable; NO = not occurring; NE = not estimated
Source: National inventory submissions and national inventory reports to UNFCCC; aggregate greenhouse gas emission data on UNFCCC website.

Table 6: Biomass energy emissions (carbon dioxide) compared to total energy and economy-wide emissions, Annex I countries

	1990	2000	2010	2014
Total biomass energy emissions ($MtCO_2$)	632	681	958	985
Solid biomass energy emissions ($MtCO_2$)	592	606	768	781
Solid as % of total biomass energy emissions	93.5	88.4	80.2	79.3
Total energy emissions ($MtCO_2$)	14,073	13,644	13,421	13,118
Solid biomass emissions as % of total energy emissions	4.2	4.4	5.7	6.0
Total economy-wide emissions ($MtCO_2$)	15,006	14,446	14,186	13,983
Solid biomass emissions as % of total economy-wide emissions	3.9	4.2	5.4	5.6

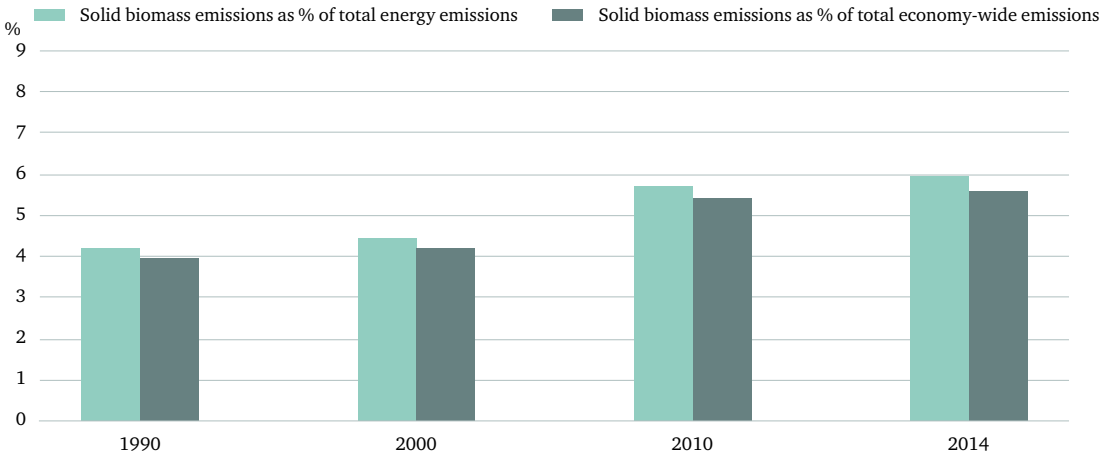
Source: National inventory submissions and national inventory reports to UNFCCC; aggregate greenhouse gas emission data on UNFCCC website.

Figure 5: Carbon dioxide emissions from biomass energy



Source: Table 6.

Figure 6: Biomass as proportion of energy and economy-wide emissions



Source: Table 6.

Table 6, and figures 5 and 6, present a summary of carbon dioxide emissions from total biomass and solid biomass in Annex I countries in 1990, 2000, 2010 and 2014, compared to total energy-sector and economy-wide emissions of carbon dioxide. As can be seen, total emissions from biomass energy and emissions from solid biomass have increased over the past two decades. While emissions from biomass have grown by more than 50 per cent from 1990 to 2014, however, emissions from solid biomass have grown by just over 30 per cent, thanks to faster rates of growth in liquid and gaseous biomass. The proportion of emissions accounted for by solid biomass fell from 93 per cent in 1990 to 79 per cent in 2014.

Nevertheless, in most countries, emissions from solid biomass constitute the vast majority of bioenergy emissions. In 2014, 23 of the 41 Annex I countries that reported having emissions from biomass-based energy derived 75 per cent or more of those emissions from solid biomass. The US accounts for almost 28 per cent of total Annex I solid biomass carbon emissions, while Germany, Japan and France account for a further 26 per cent. Neither the US nor Japan account for emissions from their land-use sectors under the Kyoto Protocol, Germany accounts against a business-as-usual projection that does not explicitly include bioenergy policies, and France uses a business-as-usual projection that includes bioenergy demand from policies up to, but not including, the 2009 EU Renewable Energy Directive. Woody biomass emissions from all these countries, therefore, have the potential to go unaccounted for.

National case studies

The UK

In 2014, the UK's total carbon dioxide emissions from fuel combustion (excluding emissions from biomass) in all sectors – energy, manufacturing and construction, transport, commercial/institutional, residential, and agriculture/forestry/fisheries – were 416 $MtCO_2$. Reported emissions from biomass energy were 28 $MtCO_2$, of which about 16 $MtCO_2$ were from solid biomass.[116] Biomass for power and heat are the most significant renewable energy sources in the UK after wind, and biomass for electricity generation has been growing rapidly, due mainly to the conversion of units at the Drax power station from coal to biomass. The UK's 2012 Bioenergy Strategy projected that by 2020 the share of biomass in power generation would account for 8–11 per cent, rising to 10–14 per cent by 2030.[117] Current demand for biomass power is in line with these projections. In 2015 bioenergy, mostly from biomass power plants, accounted for 8.9 per cent of total electricity generation.[118]

For the second commitment period of the Kyoto Protocol, the UK accounts for its domestic forest-management emissions against a projection of business-as-usual emissions based on historical planting data. The projection is based on the assumption that managed forests are harvested according to their rotation intervals, when they reach their pre-determined age of maturity. It is therefore possible to determine the future schedule of forest harvests: emissions associated with them are included in the business-as-usual baseline and, accordingly, not accounted for against the UK's emissions-reduction target. The reference level also assumes that a portion of the biomass from planned harvests – up to

[116] Solid biomass used for energy in the UK includes wood and wood waste, poultry litter and straw.
[117] UK Departments of Energy and Climate Change; for Environment, Food and Rural Affairs; and of Transport (2012), *UK Bioenergy Strategy*, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48337/5142-bioenergy-strategy-.pdf (accessed 29 Dec. 2016).
[118] UK Department of Energy and Climate Change (2016), *Renewables Statistics, Section 6: Renewables,* London: Department of Energy and Climate Change, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/579527/Renewables.pdf (accessed 29 Dec. 2016).

17 per cent – will be used for biomass energy; emissions associated with any higher use of domestic forests for energy (and, correspondingly, less carbon stored in harvested wood products) would count towards the UK's emissions target.[119]

The UK is heavily reliant, however, on imported woody biomass, primarily from the US, Canada, Latvia and Portugal. During the 12 months to the end of June 2016, it imported about 1.2 million tonnes of wood pellets from Latvia and about 0.3 million tonnes from Portugal.[120] Like many EU countries, Latvia and Portugal account for forest-management emissions against business-as-usual projections that include 'background' levels of biomass energy demand.[121] It is not possible to determine the level of forest harvests in exporting countries attributable to the UK's demand for wood pellets. However, it is likely that a portion of the emissions associated with forest biomass imported by the UK is built into exporting countries' projections, and therefore will not appear in these or any other countries' greenhouse gas accounts.

> The UK's goals for biomass-based energy production, and its continued reliance on imports, mean that an increasing quantity of emissions are likely to be excluded from the international greenhouse gas accounting framework up to 2020.

Neither the US nor Canada are parties to the Kyoto Protocol, so none of the emissions associated with the harvest and combustion of woody biomass imported from those countries are included in accounting. During the 12 months to the end of June 2016, the UK imported about 4.1 million tonnes of wood pellets from the US and 1.4 million tonnes from Canada. Assuming that all 5.5 million tonnes were used to produce energy, 7.8 $MtCO_2$ associated with this biomass was 'missing', i.e. it was not included in any country's greenhouse gas accounts under the Kyoto Protocol. (This figure is calculated using the UK's estimated emission factor, which may be an under-estimate. Using the emissions figures reported by Drax for 2013 gives a figure of 9.7 $MtCO_2$.)[122]

The UK's goals for biomass-based energy production, and its continued reliance on imports, mean that an increasing quantity of emissions are likely to be excluded from the international greenhouse gas accounting framework up to 2020. Emissions from domestic forest biomass resulting from planned forest harvests will not be included in accounting and, depending on the biomass's country of origin, emissions associated with forest biomass imported may be accounted for, partially accounted for, or not accounted for at all.

The US

The US produces the world's highest volume of emissions from solid biomass burnt for energy, although its relative contribution to the country's total energy production is fairly low. In 2014, the US emitted 293 $MtCO_2$ from the combustion of all types of biomass for energy, compared to 5,378 $MtCO_2$ from total fuel combustion across all sectors (excluding biomass emissions). The US greenhouse gas

[118] Submission *of information on forest management reference levels by United Kingdom of Great Britain and Northern Ireland in accordance with Decision 2/CMP.6,* 2 March 2011, http://unfccc.int/files/meetings/ad_hoc_working_groups/kp/application/pdf/uk_frml.pdf (accessed 29 Dec. 2016).
[120] Data based on Eurostat, http://epp.eurostat.ec.europa.eu/newxtweb/defaultquery.do.
[121] The Joint Research Centre model generates business-as-usual projections that include the effects of biomass energy policies and measures adopted before April 2009; i.e. not including the 2009 Renewable Energy Directive.
[122] The figure of 386.9 kgC/tonne biomass for wood is used in the UK's basic combustion model for the energy sector; see UK Department of Energy and Climate Change (2014), *UK Greenhouse Gas Inventory, 1990–2012: Annual Report for Submission Under the Framework Convention on Climate Change,* London: Department of Energy and Climate Change, Table A 3.2.5.

inventory calculates emissions specifically from wood used for domestic energy (including black liquor); in 2014, this amounted to 218 $MtCO_2$.[123] The industrial sector (mainly pulp and paper, wood processing, chemical production and food production) was by far the largest end user, emitting 124 $MtCO_2$ in 2014, followed by the residential sector with 60 $MtCO_2$, and electricity generation with 26 $MtCO_2$. Since the US is not a party to the Kyoto Protocol, none of these emissions are accounted for under it (though they are reported under the UNFCCC).

The US is not only a major producer of woody biomass but also a major exporter, almost entirely to the EU. Its exports of wood pellets to the EU rose from 1.5 to 4.6 million tonnes between 2012 and 2015 (about 90 per cent of which was to the UK).[124] The emissions resulting from combustion of these pellets will depend on where and under what conditions they are used. However, to the extent that the pellets were used to generate energy, the resulting emissions were not included in any country's greenhouse gas accounts. Using the US's emission factor for the combustion of wood for energy, these 'missing' emissions amounted to approximately 7.3 $MtCO_2$ in 2015.[125] (Using the Drax figures for the calculation gives emissions of 8.1 $MtCO_2$.)

This example highlights how emissions should be accounted for either in the land-use sector of the exporting country or the energy sector of the importing country, but not both. The US has indicated that under the Paris Agreement it will track its greenhouse gas mitigation, including in the land-use sector, against a 2005 baseline.[126] In 2005, US emissions from 'forest land remaining forest land'[127] were -800 $MtCO_2$ (a net carbon sink, represented as negative emissions). If the domestic or international demand for forest biomass drives an increase in forest harvests, or a more intensive use of forest residues results in increased emissions relative to the 2005 level, the fall in the forest carbon sink will be reflected as an emission (debit) in the US greenhouse gas accounts – though this could be offset by higher forest growth.

Finland

Finland's 2014 emissions from all types of biomass used for energy were 39 $MtCO_2$, almost all – 38 $MtCO_2$ – from solid biomass. This compares with 43 $MtCO_2$ from non-biomass fuel combustion across all sectors. Finland accounts for forest-management emissions in the Kyoto Protocol's second commitment period relative to a business-as-usual baseline that explicitly includes anticipated increases in emissions due to forest-based biomass energy use. The policies driving increased forest biomass demand were put in place in 2008 and therefore do not fall foul of the prohibition against including the impacts of post-2009 policies in forest-management reference levels. Finland's renewable energy policies include the goal of replacing coal in power plants with biomass and energy efficiency measures by 2025.

Finland's business-as-usual reference level includes the effects of a sharp increase in the demand for domestic roundwood. Domestic harvests in 2013 were approximately 56 million m^3, of which

[123] 'Wood' includes wood, black liquor and other wood wastes. US Environmental Protection Agency (2016), *Inventory of US Greenhouse Gas Emissions and Sinks: 1990–2014*, Washington, DC: US Environmental Protection Agency, pp. 3-90–3-92, https://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2016-Main-Text.pdf (accessed 30 Dec. 2016).
[124] Based on the US International Trade Commission's 'Trade DataWeb', http://dataweb.usitc.gov/scripts/user_set.asp.
[125] The US uses the Energy Information Administration's emission factor of 0.434 million tonnes carbon/million tonnes wood. See US Environmental Protection Agency (2016), *Inventory of US Greenhouse Gas Emissions and Sinks*, p. 3–92.
[126] US Cover Note, Intended Nationally Determined Contribution submitted to the UNFCCC in advance of the Paris conference in December 2015, and accompanying Information, 31 March 2015, http://www4.unfccc.int/submissions/INDC/Published%20Documents/United%20States%20of%20America/1/U.S.%20Cover%20Note%20INDC%20and%20Accompanying%20Information.pdf (accessed 30 Dec. 2016).
[127] The category of 'forest management' emissions is relevant only for greenhouse gas *accounting* under the Kyoto Protocol. Countries *report* greenhouse gas emissions in the land-use sector on the basis of land-use category (e.g. forest land, grassland, cropland), rather than by activity.

8 million m^3, or 14 per cent, was for direct energy use. The country's target for 2020 is to harvest 65–70 million m^3 of wood from its forests, with 12 million m^3 – approximately 17–18 per cent – harvested specifically for direct energy use.[128] Because these harvests have been included in Finland's forest-management reference level, the emissions associated with burning the resulting biomass for energy will not count against its emissions target. Using the net calorific value and emission factor for solid wood fuels supplied in Finland's greenhouse gas inventory report, 10–21 $MtCO_2$ from burning domestically harvested wood for energy will not be counted towards its emissions target.[129]

Despite Finland's plans to increase forest harvests up to 2020, its anticipated harvest volume will still remain below the forest's annual growth increment. So, even though Finland's forest-management emissions do increase relative to current levels, its forests are predicted to remain a net carbon sink.

Although Finland harvests some biomass specifically for bioenergy, the majority of wood energy in the country is the by-product of forestry-based industries. The largest single source of wood energy is black liquor, the production of which is driven primarily by demand for pulp and paper rather than demand for energy. For the remaining portion, Finland's forest-management reference level documentation indicates that it expects approximately 54 per cent of feedstock to derive from stemwood, 32 per cent from logging residues, and 14 per cent from stumps and roots. The discussion in Chapter 1 is relevant to the impact of the use of this feedstock on the climate; the length of the carbon payback period depends on what would have happened to the wood if it had not been used for energy, the rate of decay of residues, stumps and roots and other similar factors.

France

In 2014, France had the fourth highest carbon dioxide emissions from solid biomass use among Annex I countries after the US, Germany and Japan. It emitted 42 $MtCO_2$ from burning solid biomass, compared to 313 $MtCO_2$ from non-biomass fuel combustion.

France is one of the 14 EU member states whose forest-management reference levels were calculated using the European Commission's Joint Research Centre's approach. This used projections of, *inter alia*, global timber and bioenergy demand to drive its predictions of forest harvests in each of the countries modelled.[130] Although France's reference level does not include emissions from biomass used pursuant to the EU's Renewable Energy Directive, it does reflect the country's earlier decision to support the development of wood-based bioenergy by increasing domestic harvests and the utilization of sawmill residues. Because France has explicitly included emissions attributable to these bioenergy policies in its reference level; it will not count those emissions toward its emissions target.

However, France also acknowledged the difficulty of accurately predicting future demand for forest biomass, and therefore future emissions. Its reference level submission noted that, despite its goal of increasing bioenergy use, practical considerations such as mobilization costs, the price of timber and the accessibility of wood may prevent it from fully achieving this. Therefore, although the

[128] Finland Ministry of Agriculture and Forestry (2010), *Finland's National Forest Programme 2015: Turning the Finnish Forest Sector Into a Responsible Pioneer in Bioeconomy*, Helsinki: Ministry of Agriculture and Forestry, https://www2.uef.fi/documents/1192563/1939367/NFP_2015_Finlands_National_Forestry_Programme_2015_2010.pdf/544ffbb6-d760-485f-b12b-7f70a5c5ac56 (accessed 29 Dec. 2016); Matti Kahra (senior specialist, Finland Ministry of Agriculture and Forestry), personal communication with the original author of this chapter, 12 May 2015.
[129] Net calorific value for solid wood fuels = 7.8–16 GJ/t; emission factor = 109.6 gCO_2/MJ for solid wood fuels. Statistics Finland (2016), *Greenhouse Gas Emissions in Finland 1990–2014*, Helsinki: Statistics Finland, Table 3.2-4, p. 72 https://www.stat.fi/static/media/uploads/tup/khkinv/fi_un_nir_2014_20160415.pdf (accessed 29 Dec. 2016).
[130] *Submission of information on forest management reference levels by France*, April 2011, http://unfccc.int/files/meetings/ad_hoc_working_groups/kp/application/pdf/awgkp_france_2011.pdf (accessed 29 Dec. 2016).

government's goal is to increase annual harvests of woody biomass for renewable energy and timber by 12 million m^3 by 2020, the reference level conservatively assumes that harvests will actually increase by less than 5 million m^3 compared to 2010.[131] (Forest harvests in 2010 were approximately 59 million m^3, and are projected to rise to approximately 63 million m^3 in 2020.) Emissions associated with increases in forest harvests beyond the 5 million m^3 included in the reference level will therefore be counted toward France's emissions target. While this approach is still likely to result in unaccounted for carbon dioxide emissions, it should bring at least a portion of France's bioenergy emissions into its accounting framework.

Conclusions and recommendations

The international greenhouse gas reporting and accounting frameworks established under the UNFCCC and Kyoto Protocol assume that the carbon emissions associated with using woody biomass for energy are fully reported and accounted for in the land-use sector, and therefore should not be included in the energy sector. This tends to reinforce the assumption, commonly found in national policy frameworks, that biomass energy is zero-carbon at the point of use.

It is clear, however, that for the first and second commitment periods of the Kyoto Protocol, emissions from the use of woody biomass for energy have not been accurately reflected in countries' greenhouse gas accounts. The problem of 'missing', or unaccounted-for, emissions arises when a country using biomass for energy:

- Imports biomass from a country outside the accounting framework – such as the US, Canada or Russia, all significant exporters of woody biomass that do not account for greenhouse gas emissions under the second commitment period of the Kyoto Protocol;
- Accounts for its biomass emissions using a historical forest-management reference level that includes higher levels of biomass emissions than in the present; or
- Accounts for its biomass emissions using a business-as-usual forest-management reference level that (explicitly or implicitly) includes anticipated emissions from biomass energy; these emissions will not count against its national target.

In each of these scenarios, the accounting framework allows countries to avoid accounting for biomass energy emissions in both the energy and land-use sectors. However, such an absence of emissions from biomass energy is merely an artefact of the greenhouse gas accounting framework. It is a fall in emissions on paper only and does not change those emissions' impacts on the atmosphere. This risks creating perverse policy outcomes: where a tonne of emissions from burning biomass for energy does not count against a country's emissions target but a tonne of emissions from fossil fuel energy sources does, there will be an incentive to use biomass energy rather than fossil fuels in order to reduce the country's greenhouse gas emissions – even where this reduction is not 'real', in the sense that it is not accounted for in any country's land-use sector accounts.

The quantity of emissions missing from the international greenhouse gas accounting framework is impossible to calculate directly, but is likely to be significant. The data gaps and ambiguities highlighted above emphasize the need for more detailed reporting on the types, sources and countries of origin of biomass used for energy. Although many countries already collect these data, they are not

[131] Ibid.

currently available in a form that allows for a complete understanding of the impact of biomass energy use on global or national emissions.

One solution would be to account for carbon dioxide emissions from biomass burned for energy within the energy sector, not the land-use sector. While additional rules would be required to ensure emissions were not double-counted in the energy and land-use sectors, this could be a viable solution given sufficient data and guidance to promote transparency. It would, however, require a major revision of accounting rules, so it is probably more practical to keep biomass emissions within the land-use sector. Four steps could then be taken within the existing framework to reduce the potential for missing emissions.

First, all countries should include the land-use sector in their national accounting. If carbon dioxide emissions from bioenergy continue to be reflected only in the land-use sector, then the practice of allowing biomass-producing countries to exclude their land-use sectors from accounting has the potential to create major accounting gaps with potentially perverse outcomes. The entry into force of the 2015 Paris Agreement – for which many details remain to be negotiated – affords an opportunity to revise the accounting system to incentivize all countries to report and account fully for emissions from their land-use sectors, including their forests.

Second, forest-management reference levels should contain detailed information on projected emissions from using biomass for energy, the origins of that biomass (additional domestic forest harvests or increased use of domestic forestry residues) and the resulting emissions.

Third, countries that import biomass for energy should be required to report on whether and how the country of origin accounts for biomass-based emissions. Importing biomass from a country that does not account for such emissions, or from one that has built biomass energy demand into its accounting baseline, will result in 'missing' emissions and is likely to promote the importing country's potentially perverse reliance on biomass energy. Emissions associated with this imported biomass should therefore be fully accounted for by the importing country.

Fourth, countries using domestic biomass for energy should reconcile their energy and land-use sector accounting approaches in order to put emissions from each sector on a par with each other. If possible, accounting for greenhouse gas emissions in the energy and land-use sectors should use the same benchmarks – either a historical reference year/period or a business-as-usual scenario – to avoid emissions leakage between the sectors, and this should be uniform across all countries. If this is not feasible, additional methodologies and rules should be devised to bring biomass energy emissions back into the accounting framework and treated in the same way.

Although these options represent departures from current greenhouse gas reporting and accounting conventions, the scale of emissions at stake and the perverse incentives the current system creates require reform of the current system to reflect more accurately the atmospheric impacts of relying on biomass for energy.

3. Sustainability Criteria

Chapter 1 highlighted the way in which the impacts on the climate of the use of woody biomass for energy vary significantly depending on the feedstock and the way in which the forest from which the feedstock is sourced is managed. One means of avoiding (or, at least, ameliorating) these impacts is to apply preconditions that biomass installations are required to meet before they are eligible for the regulatory and financial support afforded to renewable energy sources. This topic has been under discussion within the EU for several years, and the European Commission published proposed sustainability criteria for solid biomass in November 2016.

This chapter:

- Analyses the evolution of sustainability criteria for solid biomass in the EU, including the commission's latest proposals;
- Summarizes the sustainability criteria applied to date in some EU member states;
- Looks briefly at sustainability criteria applied by governments outside the EU; and
- Analyses the sustainability criteria applied under voluntary schemes, in particular that of the Sustainable Biomass Partnership.

The EU

The EU's 2009 Renewable Energy Directive contained sustainability criteria for liquid biofuels, designed to ensure that their use delivered significant greenhouse gas savings compared to the fossil fuels they replaced (mainly for transport). There was nothing similar for solid (or gaseous) biomass, however. Instead, the directive contained a commitment to report on the requirements for such a sustainability scheme by the end of 2009.

Over the following six years the European Commission changed its view several times. In 2010 it concluded that no EU-wide criteria for solid biomass were necessary; in 2013 that they were; in 2014 that they were not; and finally in 2014 that they were. Proposals were finally published in 2016. These changes in views took place against the background of disagreements between member states. Supporters of the introduction of sustainability criteria included the main importers of biomass for energy (the UK, Belgium and the Netherlands) as well as France, Germany and Poland. Opponents tended to be those mostly reliant on their own domestic production (Austria, Finland and Sweden) that feared the potential impact on their forest industries.[132]

The European Commission's initial decision, included in a report published in 2010, that no binding criteria were necessary at the EU level was based on the wide variety of biomass feedstocks in use at the time, together with the low sustainability risks relating to domestic biomass production from wastes (municipal solid waste, post-consumer recovered wood, etc.) and agricultural and forestry

[132] See Toop, G. (2013), 'Overview of EU criteria and national initiatives', www.danskelbil.dk/~/media/Biomasse/Praesentationer/6Ecofys_GemmaToop.ashx (accessed 29 Dec. 2016).

residues, where no land use change occurred.[133] Instead, member states desiring to introduce their own national schemes were encouraged to develop them in line with the directive's requirements for biofuels. The life-cycle assessment methodology whose use it encouraged considers emissions from the cultivation, harvesting, processing and transport of the biomass feedstocks, and includes direct land-use change where the land has changed category since 2008 (e.g. from forest to annual cropland). However, the methodology does not account for changes in the carbon stock of a forest, foregone carbon sequestration of land or any indirect impacts on carbon stocks in other areas of land. The report was published when the focus of the debate on the sustainability of bioenergy was primarily on liquid biofuels rather than solid biomass, and in particular their direct and indirect impacts on land use.

A 2012 European Commission survey of the effect of national schemes found that, while 20 member states had introduced some sort of requirements covering the sustainable production or efficient use of biomass, the vast majority of these related to end-use efficiency, either requiring mandatory minimum efficiencies for the production of heat or electricity or both, or providing financial incentives to stimulate higher efficiencies or heat recovery.[134] Only the UK had introduced regulations referring to the biodiversity and land-use-change criteria recommended in the commission's 2010 report, though this did not include any criteria relating to changes in carbon stock on existing forest land. Against this background the commission became convinced that EU-wide sustainability criteria would be valuable and in 2013 a draft set was discussed internally. No agreement could be reached within the commission, however, so further development was halted.

In 2014 the European Commission reviewed the issue again and concluded that there was still no need for any EU-wide criteria since national sustainability schemes did not appear to be creating any internal market barriers and most (more than 90 per cent in 2012) biomass supply was sourced domestically, mostly from processing and harvesting residues.[135]

However, the discussions over the EU's 2030 climate and energy package and the development of the European Energy Union, as well as the growth of imports of biomass for energy into the EU and the debates over the sustainability criteria for biofuels in the light of their increasingly clear impacts on forests (which ended with the decision to remove all support for land-based biofuels after 2020), highlighted the lack of consistency between the treatment of biofuels and of biomass. Accordingly, in 2014, the commission concluded once again that EU-wide criteria would be necessary to ensure genuine greenhouse gas savings and to allow for fair competition between the various uses of biomass.[136] The biomass policy also aimed to help deliver sustainable management of forests, in line with the EU's Forest Strategy. Published in 2013, the Forest Strategy included support for the cascading use of wood as a way of maximizing resource efficiency, implying that wood should be used in the following order of priority: wood-based products, extending their service life, re-use, recycling, bio-energy and disposal.[137]

[133] European Commission (2010), *Report from the Commission to the Council and the European Parliament on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling,* Brussels: European Commission, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52010DC0011&from=EN (accessed 29 Dec. 2016).
[134] Pelkmans, L. et al. (2012), *Benchmarking biomass sustainability criteria for energy purposes,* Mol: Belgium, https://ec.europa.eu/energy/sites/ener/files/documents/2014_05_biobench_report.pdf (accessed 29 Dec. 2016).
[135] European Commission (2014), *State of play on the sustainability of solid and gaseous biomass used for electricity, heating and cooling in the EU*, Brussels: European Commission, p. 17 http://ec.europa.eu/energy/sites/ener/files/2014_biomass_state_of_play_.pdf (accessed 29 Dec. 2016).
[136] European Commission (2014), *A Policy Framework for Climate and Energy in the Period from 2020 to 2030,* Brussels: European Commission, p. 7, http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52014DC0015&from=EN, (accessed 29 Dec. 2016).
[137] European Commission (2013), *A New EU Forest Strategy: for forests and the forest-based sector*. Brussels: European Commission, pp. 4–5, http://eur-lex.europa.eu/resource.html?uri=cellar:21b27c38-21fb-11e3-8d1c-01aa75ed71a1.0022.01/DOC_1&format=PDF (accessed 29 Dec. 2016).

New proposed criteria for solid and gaseous biomass were finally published in November 2016, as part of a substantial package of policies to support renewable energy, centring on a proposed revision of the Renewable Energy Directive. The proposed criteria, which apply to installations of capacity of 20 MW and greater, include the following requirements.[138]

- The country or forest from which the forest biomass was sourced has systems in place to ensure that harvesting is carried out legally, harvested forest is regenerated, areas of high conservation value (including wetlands and peatlands) are protected, the impacts of harvesting on soil quality and biodiversity are minimized, and harvesting is limited to the long-term production capacity of the forest.
- The country from which the forest biomass is sourced is a party to the Paris Agreement and has submitted a Nationally Determined Contribution to the UNFCCC covering emissions and removals from agriculture, forestry and land use ensuring either that changes in carbon stock associated with biomass harvests are accounted towards the country's climate commitments or that there are laws in place to conserve and enhance carbon stocks and sinks. (If evidence for these requirements is not available, forest-management systems must be in place to ensure that forest carbon stock levels are maintained.)
- Minimum greenhouse gas savings compared to fossil fuels of 80 per cent for installations starting operation after 2020 or 85 per cent for installations starting after 2025 must be achieved. This relates only to supply-chain emissions, not to changes in forest carbon stock. (Suggested default values are provided for different types of feedstock and different transport distances.)
- Electricity must be produced from highly efficient cogeneration technology for installations starting operation three years after the date of adoption of the new directive (it is not clear whether this applies to old coal plants converting to or co-firing with biomass; and the delay is in any case subject to further discussion).

Member states are to be permitted to apply additional sustainability requirements over and above these EU-wide criteria. Proof of compliance with the criteria is to be provided by the plant operators, subject to independent auditing as defined by the member states. It is open to the European Commission to decide that voluntary schemes comply with the criteria (see below) and to member states to establish national schemes to do the same.

The impact assessment published alongside the draft directive explained the commission's thinking behind the proposals. It fully recognized the climate impacts of changes in forest carbon stock, noting:

> Recent studies have found that when greenhouse gas emissions and removals from combustion, decay and plant growth (so-called biogenic emissions from various biological pools) are also taken into account, the use of certain forest biomass feedstocks for energy purposes can lead to substantially reduced or even negative greenhouse gas savings compared to the use of fossil fuels in a given time period (e.g. 20 to 50 years or even up to centuries).[139]

[138] European Commission (2016), *Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast)*, Brussels: European Commission, Article 26, https://ec.europa.eu/energy/sites/ener/files/documents/1_en_act_part1_v7_1.pdf (accessed 29 Dec. 2016).
[139] European Commission (2016), *Impact Assessment: Sustainability of Bioenergy, Accompanying the document Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast),* Brussels: European Commission, p. 16, http://eur-lex.europa.eu/resource.html?uri=cellar:1bdc63bd-b7e9-11e6-9e3c-01aa75ed71a1.0001.02/DOC_1&format=PDF (accessed 29 Dec. 2016).

While considering that most current biomass use in the EU confers substantial greenhouse gas savings – since the feedstock is mostly industrial residues, harvest residues and traditional fuel wood – the commission recognized the potential for change if demand continued to grow, including additional harvesting rather than forest residue removal and the increased use of small roundwood and stumps. 'Hence, and as shown by a recent study… an increase in use of forest biomass for energy may lead to limited greenhouse gas savings or to an increase in emissions.'[140] Modelling conducted for the study also showed that, in the absence of sustainability criteria or other safeguards, growth in the use of forest biomass for energy would result in zero or small additional greenhouse gas emission reductions by 2030, or even, because of changes in forest carbon stock, an increase. And if demand continued to grow to 2050, emissions would increase in all scenarios.[141]

Despite this, however, the European Commission concluded that it was not possible to include changes in forest carbon stock in the calculation of life-cycle emissions to be used for the minimum greenhouse gas savings requirements in the sustainability criteria. Pointing to the wide variation in estimates of the climate impacts, the difficulty in attributing greenhouse gas performance to specific consignments of forest biomass and the problems of evaluating the counterfactuals, it concluded that:

> a reliable assessment of life-cycle biogenic emissions of specific consignments or pathways of forest biomass would be extremely difficult, notably because it would have to be based on subjective choices. In addition, it would pose difficulties linked to verification. Therefore, this option is discarded.[142]

Even in the absence of the inclusion of changes in forest carbon stock in the sustainability criteria, the models used in the impact assessment predicted that the proposals would lead to a slight reduction in net greenhouse gas emissions by 2030, though there was a chance of a slight rise by 2050.[143] This was due mainly to a projected fall of 3.3 per cent in total demand for bioenergy by 2030, compared to business as usual, because of restrictions on sourcing from high-risk countries (a 45 per cent fall in imports into the EU was projected in one model, a 4–19 per cent fall in another) and of increased harvesting and use of domestic roundwood within the EU, which pushed up prices for wood products. The models are subject, however, to considerable levels of uncertainty.

The European Commission considered but discarded other options for constraining forest biomass use, including the following:

- The introduction of limits on the use of forest residues, in order to protect biodiversity and soil fertility. The commission considered that this would be too difficult given the degree of variability in local conditions and, in some regions, the need to remove residues to prevent fire. In addition, it considered that 'forest residues are also normally not traded over a long distance and are not turned into pellets'.[144] (This is notwithstanding the claims of biomass companies such as Drax.)
- Promoting the cascading use of wood, in line with the EU Forest Strategy. The commission considered that a single EU-wide approach was not appropriate given the different circumstances of each member state. Non-binding guidance on the cascading use of wood is expected to be published by 2018.[145]

[140] Ibid.
[141] Ibid., p. 31.
[142] Ibid., p. 37.
[143] The impact assessment modelled the impacts of four options for constraints on biomass use. Although it did not choose between them, Option 3 is nearest to the proposals contained in the draft directive. For this option, projected cumulative changes in net greenhouse gas emissions are -8 to -34 $MtCO_2$-eq (-0.04 to -0.20 per cent) over 2021–30 and -10 to +17 $MtCO_2$-eq (-0.03 to +0.05 per cent) over the period 2031–50. Ibid., p. 47.
[144] Ibid., p. 126.
[145] Ibid.

- Applying sustainable forest-management requirements to all forest biomass, regardless of origin. The criteria proposed in the draft directive require countries or forests to have particular systems (for legality, the protection of high conservation value areas, etc.) in place rather than requiring operators to ensure that every consignment of biomass is verified as sustainably produced (probably via certification schemes). As the impact assessment explains, this is a risk-based approach designed to minimize costs to forest owners, many of whom are not certified under any forest-certification scheme.[146]

The draft directive, including the proposed sustainability criteria, has entered a period of debate and discussion between the European Parliament and member-state governments.

EU member states

Pending the development of EU-wide criteria, an increasing number of member states have developed their own for eligibility to subsidies or other support mechanisms.[147] As noted above, many member states have possessed relevant requirements for some time, including the following:

- Requirements for minimum levels of efficiency; for example, France requires a minimum conversion efficiency of at least 75 per cent, which rules out anything other than combined heat and power (CHP) plants, whereas Spain gives higher levels of support to biomass plants achieving higher energy efficiency through cogeneration.
- The provision of greater levels of support for small-scale plants; examples include Finland and Germany.
- Encouragement for or requirements that feedstock be sourced from sustainably managed forests; examples include France, Germany, Hungary and Slovenia.
- Support for domestically sourced feedstock instead of imports; examples include Austria, the Czech Republic and Italy.
- Restrictions on certain types of feedstock. For example, France does not allow stemwood; in Hungary feedstock cannot be of higher quality than firewood and no subsidies are provided for bioenergy produced from stemwood of a diameter above 10 cm; and Poland only allows the use of forestry residues and requires a minimum (increasing) share of agricultural biomass.

For all member states, domestically produced or imported woody biomass is also subject to the EU Timber Regulation (995/2010, in force since 2013), which prohibits the placing on the EU market of products that have been illegally produced and requires companies that first place wood products on the EU market to have in place a system of 'due diligence' to minimize the risk of them handling illegal material. If fully enforced, this is likely to act as a constraint on the supply of woody biomass, in particular from Eastern European countries (including, possibly, some EU member states) and Russia.

To date, the most detailed sets of criteria have been developed in Belgium, Denmark, the Netherlands and the UK. In some cases these borrow from existing public-sector procurement policies designed to

[146] Ibid., p. 37.
[147] Except where noted, information taken from Pelkmans, L. et al. (2012), *Benchmarking biomass sustainability criteria for energy purposes*; Toop, G. (2013), 'Overview of EU criteria and national initiatives'; Junginger, M. (2015) 'Sustainability regulation for solid biomass for energy in NL, BE & UK', presentation to Conference on Biomass and Sustainability, Copernicus Institute, Utrecht University 19 October 2015, Copenhagen; and Richter, K. (2016), *A Comparison of National Sustainability Schemes for Solid Biomass in the EU,* Fern, http://www.fern.org/sites/fern.org/files/comparison%20of%20national%20sustainability%20schemes.pdf (accessed 30 Dec. 2016).

purchase wood products that are legally produced and from sustainably managed forests.[148] In general they have two components – requirements for minimum levels of greenhouse gas savings compared to fossil fuels, and requirements (often called 'land criteria') relating to the legality and sustainability of forest management. Sometimes other criteria, such as restrictions on types of feedstock or on minimum plant energy efficiency levels, are also included.

Belgium

Energy policy in Belgium is devolved to the country's three regions: Brussels, Flanders and Wallonia. All three require electricity suppliers to supply a prescribed proportion of renewable energy, underpinned by a system of tradable green certificates, though the three systems are not fully compatible with each other.

In Flanders, the value of a certificate for bioenergy is calculated according to its life-cycle energy balance, whereas in Brussels and Wallonia, eligibility to green certificates depends on the greenhouse gas saving compared to the best available natural gas system. In all cases, however, changes in the forest carbon stock are ignored (i.e. the combustion of biomass is assumed to be zero-carbon); only emissions from production, processing and transport are taken into account.

In addition, in Flanders biomass streams suitable for other uses – e.g. wood that could be used by the pulp and paper or wood-processing industries, except for bark, sawdust, fine pruning wood with a diameter less than 4 cm, twigs of tree crowns with a diameter less than 4 cm, and stumps up to 30 cm above the ground – are not entitled to receive green certificates. To determine whether specific products may be used for bioenergy, the Flemish Energy Agency seeks consent from the Public Waste Agency of Flanders and the federations of the paper and wood-using industries. (Fearing competition for raw materials, Belgium's paper and wood-processing industries have been generally hostile to the expansion of the biomass energy sector). A more comprehensive set of criteria is being developed.

Wallonia requires feedstock to be 'sustainable', i.e. the use of the resource must not compromise its use by future generations. This is subject to audit.

Denmark

In Denmark, woody biomass for energy is included in the government's timber-procurement policy, most recently revised in 2014, although its application to bioenergy is voluntary throughout the public sector. The policy sets out detailed definitions of 'legal' and 'sustainable' (very similar to those in the British and Luxembourg policies). Products certified under the two main international forest certification schemes – those of the Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC) – satisfy the criteria. These schemes aim to ensure that the ways in which forests are managed and harvested meet criteria for legality and sustainability, but they do not include any criteria – such as greenhouse gas savings relative to fossil fuels – relating to the use of the products for energy.

[148] For more detail, see Brack, D. (2014), *Promoting Legal and Sustainable Timber: Using Public Procurement Policy*, Research Paper, London: Royal Institute of International Affairs, https://www.chathamhouse.org/sites/files/chathamhouse/field/field_document/20140908PromotingLegalSustainableTimberBrackFinal.pdf (accessed 29 Dec. 2016).

In 2015, in response to a request from the government, the Danish District Heating Association and the Danish Energy Association introduced a voluntary sustainability standard for biomass.[149] This includes similar requirements for legality and sustainability as the government's procurement policy, and products certified under the FSC, PEFC or Sustainable Biomass Partnership (see below) schemes are considered to meet them. The standard also requires greenhouse gas reduction levels of 70 per cent by 2015, 72 per cent by 2020 and 75 per cent by 2025, compared to fossil-fuel reference levels according to the Renewable Energy Directive methodology. This does not include emissions from changes in forest carbon stock or indirect land use change, though the industry is working to develop further criteria to cover these. The standard also aims not to use biomass where there is regionally competing demand for high-value wood resources or if the supply of those resources derives from deforestation or inappropriate conversion of forest to agriculture.

As noted, application of the standard is voluntary (and only applies to stations with capacity above 20 MW), but the associations aim to increase the level of compliance with the requirements of CHP installations (the only large-scale consumers of biomass for energy in Denmark) from 40 per cent in 2016 to 100 per cent in 2019. The standard will be reviewed in 2018.

The Netherlands

The framework for the Netherlands' renewable energy policy was set in 2013, when government, industry, unions and NGOs negotiated the Energy Agreement for Sustainable Growth, setting out the means of reaching the country's targets for renewable energy.[150] This included an upper limit of 25 PJ on energy production from biomass co-firing, and the application of sustainability criteria to co-fired biomass.

The criteria were to be negotiated by the energy sector and environmental organizations, and a first draft was published in 2015. The criteria, which apply to industrial boiler steam production from wood pellets as well as to biomass used in co-firing (though only to larger plants – dedicated biomass above 10 MW and, for co-firing, coal stations above 100 MW), include the following:[151]

- A minimum average reduction of 70 per cent of greenhouse gas emissions compared to fossil fuels, calculated according to the Renewable Energy Directive methodology. While this does not account for any changes in forest carbon stock, evidence must be provided to show that the forest is managed 'with the aim of retaining or increasing carbon stocks in the medium or long term' and with a low risk of indirect land use change.
- Restrictions on the types of feedstock: stumps are not allowed, but tops, branches, residues and roundwood are permitted, as long as on average less than half the volume of the annual roundwood harvest from the forest is processed as biomass for energy. In addition, wastes, such as mill residues or post-consumer wood waste, are permitted.
- The exclusion of biomass sourced from high-conservation-value or converted forest land or peatland or where soil and water quality have not been maintained.

[149] Dansk Energi and Danske Fjernvarme (2015), 'Industry agreement to ensure sustainable biomass (wood pellets and wood chips)', www.danskenergi.dk/~/media/Biomasse/IndustryAgreement_Biomass-20150909.ashx (accessed 29 Dec. 2016).
[150] Energie Akoord and Sociaal-Economische Raad (2013), *The Agreement on Energy for Sustainable Growth: A Policy in Practice*, http://www.energieakkoordser.nl/doen/engels.aspx (accessed 29 Dec. 2016).
[151] Netherlands Enterprise Agency (2016), *SDE+ sustainability requirements for solid biomass*, http://english.rvo.nl/sites/default/files/2016/03/SDE%20Sustainability%20requirements%20for%20solid%20biomass.pdf (accessed 29 Dec. 2016).

- Requirements for sustainable forest management, mainly taken from the country's timber-procurement policy, including the maintenance and enhancement of biodiversity and the health and production capacity of the forest and its contribution to the local economy.

A detailed system for the verification of compliance with these criteria, including elements that must be included in the sustainable forest-management system and a chain of custody system, is still under development and should be finalized in 2017.[152] The Dutch system has the most detailed of all the national sustainability criteria, and some doubt has been expressed that the requirements can actually be satisfied in practice.[153]

The UK

Since 2015 the UK has applied sustainability criteria for solid biomass under its three main support programmes for renewable energy: for electricity, the Renewables Obligation and the Contracts for Difference system that is now replacing it, and for heat the Renewable Heat Incentive.

There are two sets of criteria. The greenhouse gas criteria, which aim to account for the life-cycle greenhouse gas emissions of the biomass, include targets for emissions per unit of electricity: a minimum of 60 per cent emissions saving by 2017, compared to the 1990 level, increasing to 75 per cent savings by 2025. This is calculated according to the Renewable Energy Directive methodology, which excludes changes in forest carbon stock (apart from direct land-use change) and emissions from indirect land-use change.

The land criteria focus on the land from which the biomass is sourced. These requirements are built on the environmental and social criteria for legal and sustainable forest products contained in the government's timber procurement policy. FSC and PEFC-certified products satisfy the criteria in this respect, but since much of the biomass sourced from the US is not certified (the uptake of forest certification schemes in the US is relatively low), the regulations also allow operators to supply credible evidence of a low risk of non-compliance against all the criteria for a defined region (an area across which relevant legislation is the same, e.g. a US state) or a smaller area if they can trace it back.[154] As in the timber-procurement policy, up to 30 per cent of the biomass used in a facility can be non-compliant with the sustainability requirements (though it must be legal).

In addition, in 2013, the UK announced a cap on approvals for new dedicated biomass plants in the face of a steep increase in the number of applications. No contracts for biomass power were awarded under the first auction for the new Contracts for Difference in February 2015. The next round, which is scheduled to begin in April 2017, will be open to bids for dedicated biomass with CHP. Three contracts have been awarded without auction, however: to Drax for the conversion of its third unit and to two other power stations, one a coal-to-biomass conversion and one a new dedicated biomass CHP plant.

[152] For an outline of the proposals and responses to a public consultation on them, see Netherlands Enterprise Agency (2016), *Report on the consultation of the draft verification protocol 'Sustainability solid biomass',* http://english.rvo.nl/sites/default/files/2016/07/Report-on-the-consultation-of-the-draft-verification-protocol-sustainability-solid-biomass-June-2016.pdf (accessed 29 Dec. 2016).
[153] Griffiths, J. (2016), 'Background Paper for Scoping Dialogue on Sustainable Woody Biomass for Energy', p. 10.
[154] See UK Department of Energy and Climate Change (2014), *Risk Based Regional Assessment: A Checklist Approach*, London: UK Department of Energy and Climate Change, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/390148/141222_Risk_Based_Regional_Assessment_-_A_Checklist_Approach_-_Guidance_final.pdf (accessed 30 Dec. 2016).

Other government standards

No other national biomass sustainability standards have been developed. In many cases countries regulate domestically produced biomass for energy in accordance with their own national regulations for forestry or agriculture – and sometimes apply their timber-procurement policies – but these do not include carbon-saving requirements.

In the US, the state of Massachusetts introduced sustainability criteria in 2012. Biomass will only be eligible for subsidies under the state's Renewable Portfolio Standard if it is an eligible fuel – which includes predominantly timber harvest residues, including tops and branches, rather than whole trees – and as long as sufficient woody material is left on the forest floor to replenish soil nutrients and protect wildlife. In addition, biomass plants must demonstrate emissions reductions of at least 50 per cent over 20 years on the basis of life-cycle emissions analyses, including a carbon debt emissions factor, and must satisfy a minimum efficiency level.

Voluntary certification schemes

Voluntary forest certification systems – of which FSC and PEFC are the main global schemes – have come to act as the principal means of proving compliance with many governments' timber-procurement policies and are often used as proof of meeting some of the biomass sustainability criteria described above. These schemes do not yet contain criteria for greenhouse gas emissions and carbon stocks, however, although this possibility is under discussion. Some biomass and biomass energy companies are certified under one or both of these schemes.

Other schemes have been developed with the aim of including climate impacts alongside other criteria. The Green Gold Label standard, for example, builds on other certification systems in aiming to cover the production, processing, transport and final energy transformation of biomass.[155] Founded in 2002 and certifying biomass for the production of bio-based chemicals and other products as well as for energy, it has limited coverage: by November 2016, just 14 companies had been certified, six in the US, three in Canada and five in the EU.

The Sustainable Biomass Partnership

The main biomass certification scheme that has emerged so far is that of the Sustainable Biomass Partnership (SBP), established in 2013 by seven major European utility companies using biomass with the aim of influencing and meeting EU and member-state sustainability criteria for biomass for energy.[156] This built on the criteria included in several national timber-procurement policies and biomass sustainability requirements; some of the companies were also developing their own codes of practice for sustainable sourcing.[157]

[155] See the Green Gold Label website, http://www.greengoldcertified.org.
[156] See the Sustainable Biomass Partnership website, http://www.sustainablebiomasspartnership.org.
[157] See, for example, DONG Energy (2014), *DONG Energy Programme For Sustainable Biomass Sourcing,* http://assets.dongenergy.com/DONGEnergyDocuments/com/Responsibility/Documents/2014/DONG_Energys_Programme_for_Sustainable_Biomass_Sourcing_EN.pdf?WT.mc_id=sustainable_biomass_sourcing_2015 (accessed 30 Dec. 2016).

The SBP standard includes the following principles and criteria:[158]

- Definition of the supply base to ensure feedstock can be traced back to its source area.
- Compliance with all relevant laws, including traditional and civil rights, drawing on criteria in the UK's timber-procurement policy.
- Sustainable management of the forest and forest operations, and protection for labour and community rights, again drawing mainly on the UK's timber-procurement policy.
- 'Regional carbon stocks are maintained or increased over the medium to long term' (principle 2.9). This includes not sourcing feedstock from areas that had high carbon stocks in January 2008 and no longer have them, and sourcing only 'where analysis demonstrates that feedstock harvesting does not diminish the capability of the forest to act as an effective sink or store of carbon over the long term'.
- No use of genetically modified trees.

The SBP standard includes a calculation of the energy and carbon balance of the biomass used for energy, to be carried out by the end user using data from the supplier.[159] While this includes a requirement to record the type of feedstock (primary feedstock from forests (products or residues), woody energy crops, wood industry residues or post-consumer wood; and classification by physical form: sawdust, woodchips, roundwood, wood logs, bark, etc.) and detailed calculations of the energy used in the supply chain (harvesting, production, transport and storage), it does not include a calculation of any change in forest carbon stock.

The SBP does not set precisely what evidence must be provided to demonstrate compliance with each indicator on the grounds that this will vary among different operations, though it does include examples for each of its criteria. Verification involves a regional risk-based approach, based on a desk-based assessment against the criteria leading to a risk rating for each indicator. Where risks are identified, appropriate mitigation measures must be defined, implemented and monitored.

Risk assessments for Estonia, Latvia and Lithuania were published in 2015. Operations in all three countries were found to have a low risk of non-compliance, with risks identified with just three out of 38 criteria: possessing procedures to address potential threats to high-conservation-value areas (all three countries were found to be at risk), possessing procedures for identifying high-conservation-value areas (Latvia) and means to ensure the protection of forest workers' health and safety (Latvia and Lithuania).

No figures are yet available on the extent of the biomass energy supply chain covered by SBP certification, but given that the system was set up by several major European energy companies, it has significant potential at least in the European market. The British and Danish authorities have confirmed that SBP certification meets the requirements of their national criteria. As of the autumn of 2016, six bodies had been accredited to carry out certification against the SBP standard, and certificates had been issued to over 60 organizations.[160] This did not include Enviva, the pellet company most commonly associated with accusations from NGOs of unsustainable practices.

[158] Sustainable Biomass Partnership (2015), *SBP Framework Standard 1: Feedstock Compliance Standard*, http://www.sustainablebiomasspartnership.org/docs/2015-03/sbp-standard-1-feedstock-compliance-standard-v1-0.pdf (accessed 30 Dec. 2016).
[159] Sustainable Biomass Partnership (2016), *SBP Instruction Document 5B: Energy and GHG Data,* Version 1.1, http://www.sustainablebiomasspartnership.org/docs/Instruction-Document-5B-Energy-and-GHG-Data-v1-1-Oct16.pdf (accessed 30 Dec. 2016).
[160] See the section on 'Approvals and Certifications' on the Sustainable Biomass Partnership website, http://www.sustainablebiomasspartnership.org/approvals-and-certifications.

Conclusions and recommendations

In principle, applying sustainability criteria to the provision of regulatory and financial support to biomass energy is a potential way of tackling the problems discussed in Chapter 1, and of restricting support to those uses with zero or low carbon payback periods as well as to those where the feedstock originates from legally and sustainably managed forests.

However, the existing schemes in EU member states, the draft criteria included in the proposed new Renewable Energy Directive and the voluntary certification schemes now developing, including that of the Sustainability Biomass Partnership, are not satisfactory. Most importantly, they fail to account, comprehensively or at all, for changes in forest carbon stock (apart from direct land-use change), which, as discussed in Chapter 1, is a crucial element in determining climate impacts. Effectively, these criteria permit the provision of financial and regulatory support to policy options that could increase carbon emissions in the short, medium and possibly long term.

The requirements in the Dutch criteria that the forest is managed 'with the aim of retaining or increasing carbon stocks in the medium or long term', and in the SBP's standard that 'regional carbon stocks are maintained or increased over the medium to long term' are too vague. Forest carbon stock levels may stay the same or increase for reasons entirely unconnected with use for energy; the important issue is what levels they would have reached in the absence of biomass energy use. In addition, as discussed in Chapter 1, from the point of view of mitigating climate change, there is a major difference between the medium term and the long term; arguably, anything longer than the short term is too long.

The inclusion in the draft new Renewable Energy Directive of a requirement for the country from which the forest biomass is sourced to be a party to the Paris Agreement that accounts for changes in carbon stock associated with biomass harvests is a step in the right direction, ensuring that the emissions resulting from the biomass use count against climate targets. However, the phrase 'accounted towards the country's climate commitments' needs to be carefully defined. As explained in Chapter 2, the choice of forest baseline against which countries account can mean that some biomass-related emissions effectively go unaccounted for. In addition, as discussed in Chapter 1, the full climate impact of the use of forest residues may be significantly underestimated in current models, given its potential effects on soil carbon levels and tree growth rates. If a country is not a party to the Paris Agreement or does not account for biomass-related carbon stock changes, the draft criteria specify that laws must be in place in the country of origin to 'conserve and enhance carbon stocks and sinks'. This begs the same kind of questions as the terminology used in the Dutch and SBP criteria discussed above, and is equally unsatisfactory.

Robust sustainability criteria must deal with the impact on greenhouse gas emissions as well as the legality and sustainability of forest management. One option would be for the greenhouse gas element to be underpinned by a comprehensive life-cycle analysis for each type of feedstock, including changes in the forest carbon stock alongside supply-chain emissions associated with harvesting, processing and transport (including methane emissions from storage, as discussed in Chapter 1). This is not a straightforward process – varying with the type of tree species, the location of the forest, the characteristics of the technology involved, transport distances and so on – but the UK's BEaC calculator, among other means of estimating payback periods, provides a potential methodology. A similar approach could be applied to calculate default values for different biomass feedstocks (the draft Renewable Energy Directive contains default values, but only taking into account supply-chain emissions). However, as discussed in Chapter 1, the impact of biomass

energy use also depends on the counterfactual: what would have happened to the wood, and the forest from which it was sourced, if it had not been used for energy? Since this is not a fixed element, it is virtually impossible for sustainability criteria to incorporate it.

A more practical approach would be to limit the types of feedstock that can be used, as several EU member states and the US state of Massachusetts already do. The aim would be to restrict eligibility for support to those feedstocks that are most likely to reduce net carbon emissions (or have low carbon payback periods): primarily mill residues, together with post-consumer waste. Fast-decaying forest residues could also fit into this category, but in practice this is small-diameter material that is likely to contain too much moisture and dirt to render it usable by biomass plants; and it would be very difficult for policy to distinguish easily between fast and slow-decaying residues.

An additional element could be a requirement for a minimum level of efficiency of the plant in which the biomass is burnt (again, as in a number of EU member states and, for new installations, in the draft Renewable Energy Directive), maximizing the energy delivered per unit of carbon emitted. In practice, this should restrict financial and regulatory support for biomass use to combined heat and power installations.

Even when restricted in this way, policies should ensure that subsidies do not encourage the biomass industry to divert raw material (such as mill residues) away from alternative uses (such as fibreboard), which have far lower impacts on carbon emissions. This may require the sustainability criteria to be adjusted from time to time depending on market conditions. The cascading principle included in the EU Forest Strategy, in which combustion for energy is the last use of wood after a series of other uses, is a good one and it is regrettable that it is not reflected in the new draft Renewable Energy Directive.

Alongside these emissions criteria, land criteria – applying the same kind of requirements for legal and sustainable sourcing already found in many timber-procurement policies and the FSC and PEFC – play an important role in protecting the way in which the forests are managed. Most national and voluntary sustainability criteria already contain these kind of requirements, but they face a problem in sourcing from areas such as the US southeast, where the uptake of forest certification is very low and most forests are largely unregulated. It remains to be seen whether the risk-based approach found in the UK requirements, the SBP standard and the draft Renewable Energy Directive can deliver products that reliably meet the criteria. Desk-based assessments should be supplemented by on-the-ground inspections, ensuring, for example, that support is not given where whole trees are used, and in particular where old-growth forests are being logged for energy or converted to plantations.

Conclusion

The use of woody biomass for energy cannot be considered to be automatically carbon-neutral under all circumstances, though most policy frameworks treat it as though it is. In reality, carbon dioxide and methane will be emitted from the combustion of woody biomass (generally at higher levels than from the fossil fuels it replaces) and from its supply chain of harvesting, collecting, processing and transport. In addition, where the feedstock derives from harvesting whole trees, net carbon emissions will increase from the foregone carbon sequestration that would have occurred had the trees been left growing.

Some types of biomass feedstock can be carbon-neutral, at least over a period of a few years, including in particular sawmill residues. These are wastes from other forest operations that imply no additional harvesting, and if otherwise burnt as waste or left to rot would release carbon to the atmosphere in any case. Black liquor is a waste from the pulp and paper industry that would otherwise have to be disposed of. It can make sense to burn these types of woody biomass for energy (particularly on-site, with no need for processing or transport), and in any case in many instances this will be economic without the need for subsidy. Fast-decaying (small-diameter) forest residues are unlikely to be usable by biomass plants, and burning slowly decaying forest residues for energy may mean that carbon emissions stay higher than if fossil fuels had been used for decades, which is a matter of considerable concern given the current rate of global warming. If mill residues are diverted from use as wood products to use as energy, net carbon emissions will be higher as a result.

Policies providing financial and regulatory support to woody biomass should discriminate between the different feedstocks on this basis. It cannot make sense to support practices that raise greenhouse gas concentrations over the short, medium and sometimes long term. Yet this is precisely what most existing policy frameworks do, ignoring changes in forest carbon stock and providing support to all biomass feedstocks irrespective of their impact on the climate. The international rules designed to account for changes in forest carbon levels in the land-use sector do not do this comprehensively, and some of the emissions from woody biomass may go unaccounted for.

Although comparisons are generally made between the use of woody biomass and the use of fossil fuels, particularly coal, in practice biomass energy may be more likely to displace other sources of renewable energy rather than fossil fuels. This is particularly the case where governments have adopted national targets for the growth of renewables (as in the EU) and where they have limited budgets for providing subsidies (as in, for example, the UK). In these cases, if biomass is not available, is constrained by sustainability criteria or is not subsidized, other forms of renewable energy may grow faster. (This raises questions of the costs of competing renewables – which for many, particularly wind and solar PV, are falling much faster than those of biomass – and the role of biomass as a system balancer, being a dispatchable rather than a variable source – which will be considered at more length in the companion paper, *Woody Biomass for Power and Heat: Global Patterns of Demand and Supply*.)

For all these reasons, current biomass policy frameworks are not fit for purpose. Sustainability criteria should be used to restrict support to mill residues that are produced from legal and sustainable sources (as defined in many timber procurement policies and forest certification schemes) and do not divert raw material away from wood products. This requires substantial changes in current policies in the EU and elsewhere to ensure that biomass policies contribute to mitigating climate change rather than exacerbating it.

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From 2010 to 2012 he was special adviser at the UK Department of Energy and Climate Change; before that he worked for Chatham House, and from 1998 to 2003 was head of its Sustainable Development Programme.

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Attachment 6

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Multi-functionality and sustainability in the European Union's forests

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This report can be found at
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Science Advice for the Benefit of Europe

EASAC

EASAC – the European Academies' Science Advisory Council – is formed by the national science academies of the EU Member States to enable them to collaborate with each other in giving advice to European policy-makers. It thus provides a means for the collective voice of European science to be heard. EASAC was founded in 2001 at the Royal Swedish Academy of Sciences.

Its mission reflects the view of academies that science is central to many aspects of modern life and that an appreciation of the scientific dimension is a pre-requisite to wise policy-making. This view already underpins the work of many academies at national level. With the growing importance of the European Union as an arena for policy, academies recognise that the scope of their advisory functions needs to extend beyond the national to cover also the European level. Here it is often the case that a trans-European grouping can be more effective than a body from a single country. The academies of Europe have therefore formed EASAC so that they can speak with a common voice with the goal of building science into policy at EU level.

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Science Advisory Council

Multi-functionality and sustainability in the European Union's forests

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Foreword

The European Academies' Science Advisory Council's (EASAC's) mission is to help policy-makers in European institutions gain access to the latest science and technology related to contemporary policy issues. Often this involves working at the frontiers of science and technology where new capabilities raise new regulatory issues, but equally sectors covered by long-established laws and regulations may need revision as a result of new knowledge or societal priorities. Forestry is one such sector with a history going back hundreds of years and regulatory structures ranging from local through national to European (and global) scales. However, recent shifts in society's demands and substantial improvements in our knowledge of forest ecosystems and the potential contribution of ecosystems services to society's needs have called into question the adequacy of historical regulatory structures. As a result, there are several forest-related policy issues currently under debate within the European Union (EU).

Forests offer important opportunities for wealth and job creation in rural areas, as well as crucially important habitats for many endangered species of fauna and flora and protection from natural hazards such as erosion, landslides, avalanches and flooding. They attract visitors and tourists wishing to enjoy a growing range of leisure activities, while also contributing to the mitigation of global warming. Forests can be managed and harvested in different ways to produce forest biomass, which can be made into a wide range of products including timber for construction and furniture, pulp for making paper, and a growing number of biochemical, bioplastics and fuels. Forests differ widely across the EU because of differences in climate and in forestry traditions and policies. In addition, forests are changing in many parts of the EU because of the effects of climate change, which include higher temperatures, lack of rainfall, wildfires, damaging storms, diseases and insect infestations.

Reflecting this current situation, EASAC welcomed an offer by the Finnish Academy of Science and Letters to lead a special project focusing on the sustainability and multi-functionality of Europe's forests. EASAC Council adopted this project in late 2014 and over half of EASAC's member academies nominated experts to review the relevant science. These experts covered a wide range of disciplines, and provided geographic coverage from the Mediterranean to the Arctic, and from Portugal in the west to Hungary in the east. This expert group provided a strong scientific foundation for EASAC to develop this report, which reviews recent scientific knowledge, analyses its relevance to policy and presents concise evidence and conclusions for use by EU policy-makers.

The evidence confirms that there are important conflicts between the competing demands being made of Europe's forests and the finite resources and services that they can offer. In the context of EU policy-making, it is important to recognise that several different international agreements and policy areas have an impact on EU forests, even though they may not be labelled as forestry policies: for example, the Paris Agreement on climate change, and the Convention on Biological Diversity. Moreover, when looking to the future it is clear that targets, such as those proposed in the recent EU package on 'Clean Energy for all Europeans', could have major impacts on the future of EU forests and need to be taken into account when making or updating national policies for sustainable forest management. Our analyses indicate that only by adopting a coherent and holistic approach will be it possible for EU policy-makers to maximise the value of the multiple functions of forests and to deliver the optimal social, environmental and economic benefits from this finite resource.

I express my thanks on behalf of EASAC to Professor Jaana Bäck from the University of Helsinki, who chaired the working group and played a key role in drafting this report together with the EASAC Environment and Energy Programme Directors. I also thank the experts from EASAC member academies who contributed directly to this report, and the officials from five Directorates-General of the European Commission who kindly provided information and evidence that informed the discussions leading to the policy advice contained in this report.

An important aim of publishing this report is to stimulate further discussions between policy-makers and stakeholders who are working in areas that could impact on the future of EU forests. EASAC and its member academies encourage such discussions in Brussels and in EU Member States, and will be pleased to contribute to such discussions.

Thierry Courvoisier
EASAC President

Summary

Although forest management policies remain the responsibilities of Member States, EU policy already recognises the interplay of different aspects and policy objectives within the common theme of 'forests': in wealth creation and employment, natural resources and raw materials, nature conservation and biodiversity, mitigation of and adaptation to climate change, and in energy and agriculture. Consequently, some 10 Directorates-General in the European Commission are responsible for policies that concern forests. This creates a significant challenge to policy-makers to ensure a systematic approach, to avoid conflicts and to enhance sustainability and synergies between different policy domains. In particular, recent decisions in the Convention on Biological Diversity and the Paris Climate agreement require fast and firm actions related to the use and management of forests and their products. Such global objectives require that national, regional and global policies are consistent with each other.

These global objectives are set against a background of additional factors.

- Shifts in the demands and expectations from forests, and a broadening in the potential markets for woody biomass (including biorefining and bioenergy).
- Forests are increasingly influenced by stakeholders from many parts of society, with varying interests some of which compete with each other.
- Forestry resources are affected by several factors which have not yet been taken fully into account in national or international policies; for example, diseases, invasive species, climate change and land use changes. Knowledge and evidence concerning the non-market ecosystem services provided by forests is increasing, including that on climate change mitigation through carbon storage, conservation of biodiversity and protection against erosion.

With a significant increase in scientific knowledge over the past decade, EASAC undertook this study, led by the Finnish Academy of Science and Letters together with a wide and multidisciplinary expert group, to review current scientific knowledge and consider how the multiple functions of forests can be managed sustainably to deliver the optimal social, environmental and economic benefits from this finite resource. In particular, this report focuses on scientific knowledge related to the many factors contributing to forests' interaction with climate change, and the ways in which different policies and management structures may interact with biodiversity.

The interaction of forests with climate change is complex. The function given the highest priority in the 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) is to manage forests sustainably so as to enhance forest carbon stocks to help mitigate climate change. EU forests are already contributing to this through their annual increment of wood, which is currently equivalent to an uptake of about 100 million tonnes of carbon annually (approximately 10% of Europe's fossil fuel emissions). However, science suggests that the processes underlying this may be transient and that the forest-based carbon sink has an upper limit, which may already have been reached in some areas. Nevertheless, potential may still exist for increasing the carbon sink of European forests through well-designed management. Here, while younger, faster-growing forests may have a higher **rate** of carbon uptake from the atmosphere, it is the older, longer-rotation forests and protected old-growth forests that exhibit the highest carbon **stocks**.

The overall impacts of forests on the atmospheric carbon budget depend heavily on the uses made of the harvested forest products (wood). Where the wood is captured in construction or other long-term uses, its carbon is kept out of the atmosphere for long periods and the demand for other carbon-intensive materials such as steel or concrete is reduced. In contrast, the use of wood in bioenergy releases its carbon to the atmosphere very swiftly. In assessing overall climate impacts therefore, the whole chain from forest ecosystem to wood products and energy substitution needs to be taken into account. In addition, forests influence climate by biophysical processes, such as cloud formation processes and albedo, which depend on tree species diversity, stand density, types of forest management and location. Depending on the combination of the above factors, the impacts of forests on global average temperatures can be positive or negative. This report examines aspects related to the net effect of forests on climate, including the net effects on climate of using forest biomass as a source of fuel and its comparison with fossil fuels.

This report also examines the need to recognise the importance of different ecosystem services provided by Europe's forests. These include some services that are valued by the market (for example tourism and recreation), but many that are not assigned a market value. Some 65 million EU citizens harvest mushrooms, berries and other wild foods; forests provide habitats for diverse fauna and flora (including game for the EU's 13 million hunters), protection from natural hazards such as erosion, landslides, avalanches, flooding,

and poor water and air quality. These services are underpinned by biodiversity, which increases resilience to the impacts of environmental change and forests' ability to provide such services.

This report points out that the principles of sustainable forest management (SFM) applied in the EU recognise the multi-functionality of forests and the need to maintain the ecological functions of forests and their ecosystem services, while fulfilling their economic and social functions. However, Europe's forest ecosystems are already under pressure due to existing impacts of climate change and forest management, and are expected to become more stressed in the future. In addition to climate change, human efforts to mitigate and adapt to climate change can both positively and negatively affect biodiversity and other ecosystem services. Our analyses thus shows tensions between some of the objectives of SFM—especially between demands for increased extraction of biomass from forests and the contributions made by the same biomass *in situ* to soil fertility, biodiversity and protective functions. Other synergies and trade-offs exist in the way in which forests' interaction with climate change mitigation is managed.

The report reaches several important conclusions.

- Biodiversity underpins the ecosystem services of forests, and a decline in biodiversity threatens the ability of both managed and natural ecosystems to adapt to changes in their environment. This links the sustainability of forest management to both conservation of biodiversity and climate impacts, as diverse ecosystems are often more efficient in providing climate change mitigation.

- The role of forests is particularly important for biodiversity, and action is required to protect the remaining critical habitats (old-growth forests), restore already degraded areas, as well as to include more biodiversity considerations in forest management. Tools to meet biodiversity conservation targets vary between eco-climatic regions, but improved coordination between national biodiversity protected areas is required.

- Public and private forest owners increasingly recognise the multiple use of forests and their ecosystem services. This is generating a need for a new, diversified forest management approach that potentially conflicts with policies that focus narrowly on raw materials provision.

- The climate impact of forest management is not just related to their effects on atmospheric carbon, since changes in albedo, other greenhouse gases and cloud formation can be significant. Forest management from a climate perspective should incorporate such biophysical effects. Increasing the carbon storage in existing forests is a cost-effective measure to decrease net carbon emissions, but EU policies are currently biased towards the use of forest biomass for energy with potential negative effects on the climate over the short to medium term. The economic principle that '*cleaner earns, polluter pays*' suggests that carbon storage should be subsidised and emissions from forest bioenergy should be fully accounted for and controlled through appropriate means.

- A critical factor in the use of forest biomass in energy provision is the 'payback time', during which atmospheric concentrations of carbon dioxide (CO_2) will be increased as a result of using biomass. EASAC concludes that the European Commission should consider the extent to which large-scale forest biomass energy use is compatible with UNFCCC targets (of limiting warming to 1.5 °C above pre-industrial levels), and whether a maximum allowable payback period should be set in its sustainability criteria.

- Since using wood in durable commodities and construction allows carbon to be stored over long periods, these uses should be stimulated. At the end of their life, the same wood can then be used for bioenergy (and/or biorefining) within the framework of a cascade approach.

- A critical feature in the current policy implementation of the EU carbon accounting procedure is how the future forest reference levels for the Member States are specified. These should be set on scientifically objective grounds and incentivise climate change mitigation.

- EASAC agrees with much of the European Commission's recent analysis on the underlying issues related to the role of forest biomass for energy and that the primary purpose of biomass energy is climate change mitigation. Compared with some other renewable energy sources, the impact of biomass energy on levels of carbon dioxide in the atmosphere is very poor, and renewable subsidies should reflect this.

- Other issues covered in the report include short rotation forestry, accounting procedures used in the land use, land-use change and forestry (LULUCF) sector, the possibility of payments for ecosystem services, and general SFM practices contributing to both biodiversity conservation and climate change mitigation.

Overall, the current scientific evidence on forests' role in climate change and on the current status of both biodiversity and forest vitality has significant implications for future forest policies and management.

Policies should better account for the multi-functionality of forests and should better optimise the balance between social, economic and ecological contributions. To find a better balance between the competing demands on Europe's forests may require different management approaches based on *local* scientific evidence. Forest management approaches in one region may not be directly transferable to other forest climatic zones: for example, the impacts of forest management strategies such as continuous cover silviculture and the enhancement of native tree species diversity and landscape heterogeneity may contribute to different extents to the maintenance of forest cover, the conservation of carbon stocks and biodiversity, and the improvement of the social and cultural values of forests.

A final word

Debate on the European Commission's 2016 energy package (EC, 2016a) offers an opportunity to address the core issues raised about forests' sustainability and multi-functionality. These include better management of carbon stocks, enhancing forest biodiversity and ecosystem services, while ensuring forest biomass use delivers real reductions in greenhouse gas emissions over a period that is meaningful from a climate perspective. Through its own independent studies and through the EU Science Advisory Mechanism (SAM), EASAC looks forward to continuing to provide scientific input to support the Commission's policy development process.

Background

The EU has a vision of sustainable forestry contributing to the economy of its Member States and to the environment—both regionally and globally. In the latter context, the role of forests in biodiversity conservation and climate change mitigation has become increasingly important through the United Nations Convention on Biological Diversity (CBD) and the UNFCCC.

Forests in the EU's 28 Member States stretch from the Atlantic in the west to the Black Sea in the east, and from the Mediterranean in the south to the Arctic in the north. Forest management has evolved at a national or sub-national level influenced by the quantity and nature of the forest resources available, forecasts on their future development, impacts of demand, and local economic and social factors. The evolving management of forest resources has been affected in recent years by substantial shifts in the demands and expectations from forests as a resource, while the forest resource itself is subject to new pressures which are not yet sufficiently taken into account in national or international policies. These pressures include diseases, invasive species, and the effects of climate change on forests through drought, increasing temperatures, storms and other forms of extreme weather.

Many forests continue to provide the traditional forest products of timber, pulp, paper, etc., but forested areas are also expected to provide important ecosystem services, including climate change mitigation, conservation of biodiversity, recreation and protection against avalanches and erosion. A key policy issue is how the existing and future forests in the EU, which are limited in size and have a fragmented ownership, should be managed to deliver in a sustainable way an optimal mix of social, environmental (including biodiversity conservation) and economic services. The management options selected may lead to many different outcomes depending on the initial state of the forest, and the end use of the harvested wood, so that complex trade-offs may emerge. For instance, some management actions may increase a forest's future potential for carbon capture and storage, while others may release previously bound carbon into the atmosphere.

Such interactions call for a multidisciplinary approach to the physical, chemical and biological, as well as social and economic, aspects of forestry; a key consideration in forest management is thus their multi-functionality. However, not all forests provide the same range of functions; nor may they all be available at the same time. There can thus be important trade-offs or win–win options when formulating forest management policies from the perspective of multi-functionality. Forest management may thus benefit from a more systems approach, where scientific understanding provides inputs to policy tools that guide the optimal use of forest resources.

In response to this perceived need, EASAC, with the support of the Finnish Academy of Science and Letters, decided to undertake this study to collate the underlying science related to the most important functions of EU forests and their management, and to provide advice and guidance from a scientific perspective on how to move towards an optimal mix of functions and services from the EU's forests.

This project has been guided by an expert group, nominated by the Academies of Science in 14 countries (see Annex 1)[1]. Following initial reviews to identify areas of significant recent science, the expert group decided to concentrate on two of the current EU policy priorities to which forests are increasingly being required to contribute, namely climate change impacts/mitigation and biodiversity conservation, and to examine their links to forest policies.

The report begins with a short overview of the current state and uses of Europe's forests, explains how forests are reacting to the changing climate, and then focuses (Chapter 3) on biodiversity conservation and the trade-off between biodiversity, traditional forest management and the rapidly growing bioenergy production. The ways in which forests interact with climate and can be both a sink for, and source of, greenhouse gases and other climate-forcing effects are discussed in Chapter 4. The report then addresses (Chapter 5) the potential for optimising forest management in different parts of the EU, taking into consideration the potential for trade-offs between various targets which have been set by the EU alone and in international treaties, and which depend on contributions from European forests. Finally, conclusions and recommendations are presented which address potential EU policies related to the sustainability and multi-functionality of European forests.

[1] The project was led by the University of Helsinki on behalf of the Finnish Academy of Science and Letters, and three workshops were held to identify critical policy issues, view the latest science and refine the report.

1 Introduction to the EU's forests

1.1 Key characteristics of Europe's forests

Forests cover approximately 42% of the land area in the EU (161 million hectares (1 hectare = 10^4 m^2); Forest Europe, 2015) which is about 5% of the world's forests. About 87% of European forest area is classified as semi-natural, 4% natural and 9% as plantations. While approximately 25% are protected under Natura 2000 legislation, overall only 2% can be considered strictly undisturbed. Most undisturbed forests are found in Northern and Central-East Europe (Food and Agriculture Organization of the United Nations (FAO), 2015).

Forest ecosystems in the EU are diverse, spanning several climatic and biogeographic zones[2] of which the boreal, Mediterranean and temperate (Atlantic and continental) zones constitute 87% of the land area. Each zone exhibits different species, growth rates and contrasting management traditions, which have evolved over hundreds of years. The climate, soil and hydrological factors determine the potential climax vegetation[3] and, combined with past and present human impacts, have resulted in the present-day variety of forest types. There are various existing schemes of forest classification; one showing the distribution of the main tree species is shown in Figure 1.1 (Brus *et al.* 2011).

More detailed information on various forest types[4] is given in Box 1. It can be seen that forest categories are distributed rather differently among the 28 EU Member States. Not only does the total forest area per country vary greatly but also the distributions of the various forest types are different. Box 1 highlights the connections between forest categories and the political units that administer them, and the inherent complexity of European forest management.

Box 1 also provides information on forest ownership, statistics related to its use and ecosystem services. This shows profound regional differences: for example, the importance of other wooded lands in the south, the vastness of the Northern forest, and the higher growth rates of Central European forests. Note also the different importance of ecosystem services such as erosion control in mountainous countries, and the prevalent low degree of naturalness in some countries. By volume, more than half the EU forest is coniferous and about 60% of EU forest area is privately owned. Current management practices vary widely according to forest type and the local approaches developed to suit the landscape and the type and rate of forest production. These practices range from felling and extraction of wood to harvesting forest products from standing trees (for example cork, acorns for livestock). Management regimes typically include, for example, clear-cut harvesting (including periodic thinning, and covering larger or smaller areas) in the Nordic countries, plantation forestry in some parts of southern and western Europe, continuous cover management,

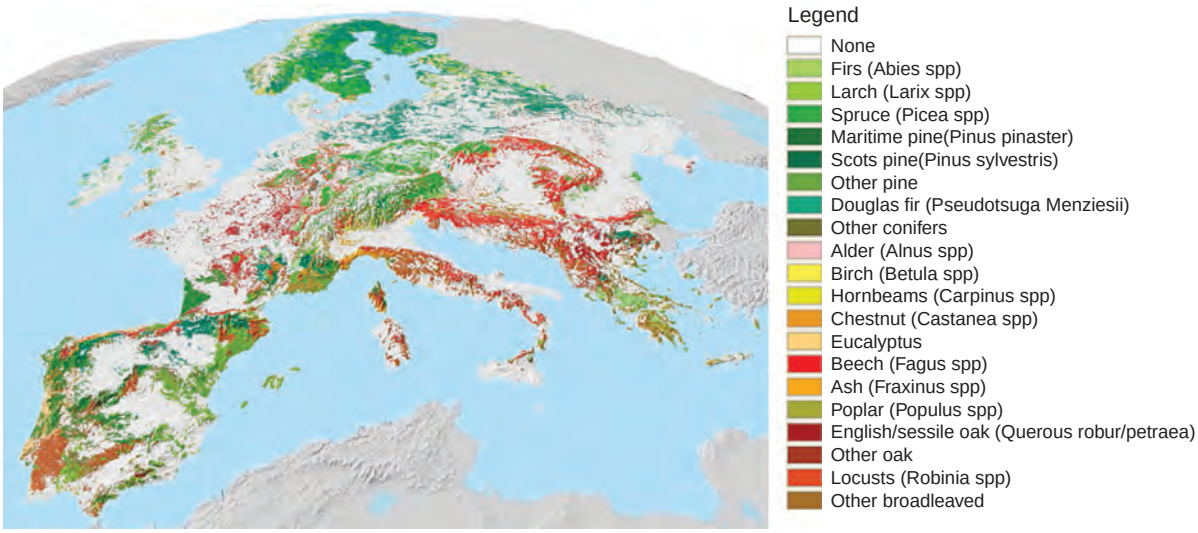


Figure 1.1 Tree species map of EU forests across Europe (reproduced from Brus et al., 2011).

[2] The European Environment Agency assigns the EU's biogeographical zones to Atlantic (18.4%), Boreal (18.8%), Continental (29.3%), Alpine (8.6%), Pannonian (3.0%), Steppic (0.9%), Black Sea (0.3%), Mediterranean (20.6%) and Macaronesian (0.2%).

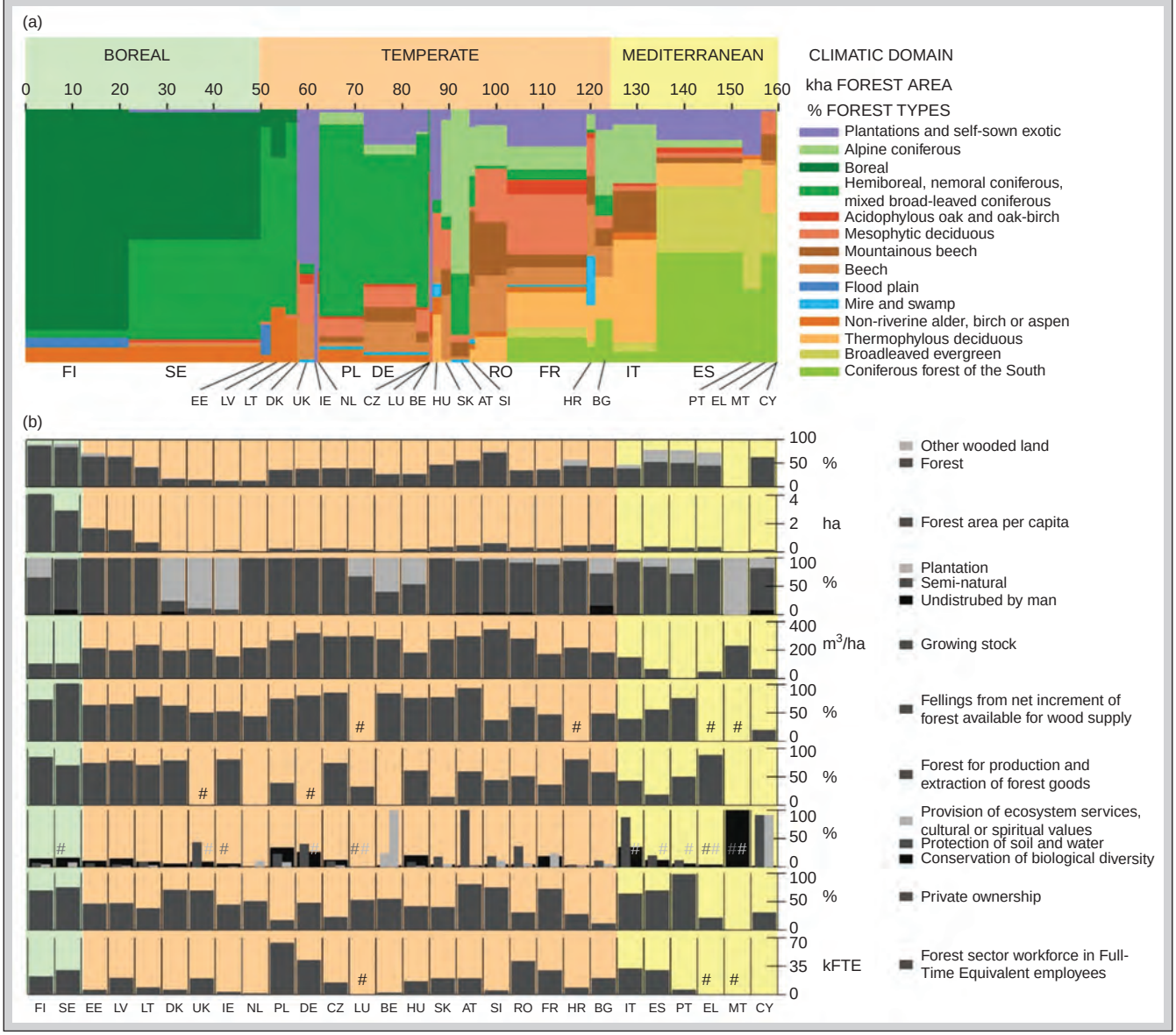
[3] Ecosystems are always dynamic but climax vegetation is understood to be one that, through the process of ecological succession in any given area over time, reaches conditions approaching an apparent steady state.

[4] Using a classification system adopted to assist the Ministerial Conference on the Protection of Forests in Europe in the assessment of sustainable forest management.

Box 1 Characteristics of the forests the 28 EU Member States

The upper panel (a) in the figure below shows the total size of the forest area and how it is distributed through the major climatic zones (categories of the FAO). Several biogeographical regions span the area but are not shown here for simplicity. Within each climatic zone, proportions of 14 forest types (right) are depicted both for the total forest area and within countries, according to the European Environment Agency (EEA, 2006). (The width of the columns indicates the area in each country while the colours indicate the different forest types.)

The lower panel (b) shows per-country values (relative to the total forest area of that country) of some key indicators on forest characteristics (share of forest over total country area and the comparison with other wooded land, forest area per capita, and the degree of naturalness); production (growth and share of increment that is actually felled); forest use (share of forest designated for production and for protective functions); socio-economic context (private ownership and the forest sector workforce). Values are for 2015 (if not available, 2010); missing values are marked with a hash symbol (#). Data were gathered from FAO (2015) and Forest Europe (2015).



retention forestry (integration of biodiversity concerns in production forests) and forests without active management in several Central European locations (Gustafsson *et al.*, 2012; Nabuurs *et al.* 2015).

Especially in Sweden, Finland, Norway, Poland, Austria and the Baltic countries, forestry plays an important economic role. Forests in Central European countries have high stocks and higher annual increments compared with the European average. South-west European forestry includes a diverse range of practices, from Atlantic plantations of exotic species to dry Mediterranean forests of low productivity and low rates of management, but which at the same time provide many ecosystem services, agroforestry and protect against desertification. The Mediterranean forests are at the same time expanding their cover and being threatened by forest

Box 2 Sustainable Forest Management

Sustainability has been a concept in forestry for centuries in the context of ensuring that harvest should not exceed new growth to secure a regular long-term production of wood products. This has progressively expanded to accept that forest management should not just focus on timber as a commercial product, but that it should aim at a broader provision of human-valued products and services (Kuhlman and Farrington, 2010). Since the Brundtland Report of 1987, 'sustainability' has become associated with the United Nations definition which recognises that '*Economic development, social development and environmental protection are interdependent and mutually reinforcing components of sustainable development*'. Following several Ministerial Conferences on the Protection of Forests in Europe, the term 'sustainable forest management' (SFM) was defined in 1993 as '*the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems*' (Helsinki Resolution H1). In addition, Forest Europe has provided guidelines for pan-European criteria for SFM, which include indicators and monitoring (Lisbon Resolution L2). These criteria and indicators have been continuously revised, and six criteria were adopted by the 46 Member States to the 7th Forest Europe Ministerial Conference in 2015, shown in the Table below.

Pan-European criteria for Sustainable Forest management

1. Global carbon cycles	Maintenance and appropriate enhancement of forest resources and their contribution to global carbon cycles
2. Health and vitality	Maintenance of forest ecosystems' health and vitality
3. Productive functions	Maintenance and encouragement of productive functions of forests (wood and non-wood)
4. Biological diversity	Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems
5. Protective functions	Maintenance, conservation and appropriate enhancement of protective functions in forest management (notably soil and water)
6. Socio-economic functions	Maintenance of other socio-economic functions and conditions

fires, exacerbated by increased temperatures and drought events associated with climate change and increased pressure from human activities. Non-wood products and services (for example edible products, grazing, tourism) are often important, although not always properly valued.

1.2 Sustainability and the use of forests, forest services and products

Northern EU countries are areas of traditionally intensive forest management with a dynamic forest sector and innovative technological developments in the timber industry. In contrast, Southern Europe exhibits a lower level of economic activity in forestry and the timber industry, and few systems for the remuneration of social and environmental services that may well be of greater importance than timber production. Nevertheless, forest management (for example for grazing and harvesting of firewood) and its impact on the structure of the forest can still be high.

Adaptive capacity in the forestry sector is relatively high in the boreal and temperate oceanic regions. In the temperate continental region of Eastern Europe, adaptive capacity in the forest sector is restricted by socio-economic constraints, such as a lack of investment in forest enterprises or the timber industry, an under-developed legal system to secure sustainability of forest management, and a lack of infrastructure to access the forest resource and adapt forest management to changing market conditions.

Currently, the forestry sector is undergoing large structural changes in many Member States, to accommodate changes in the demand for wood, paper and pulp, the emergence of the green economy/bioeconomy, as well as moves towards a circular economy (EASAC, 2015) and decision-making based on value cascading (Olsson *et al.*, 2016; Ciccarese *et al.*, 2014). The latter principle implies the priority use of wood material based on the higher added values that can be generated along the wood value chain, where the use of wood for energy (after recycling opportunities to produce other products have been exhausted) is typically the least valuable option[5].

A key underlying factor is an expectation that the use of forests should be 'sustainable', where the importance of managing forests and forest lands in a sustainable way has been recognised internationally by the United Nations and the EU at ministerial levels. Management guidelines and indicators for performance monitoring have been published by the EU, with the aim of maintaining the biodiversity, productivity, regeneration capacity and vitality of forests as well as their potential to fulfil relevant ecological, economic and social functions (see Box 2).

[5] The use of the wood cascade is stressed in the Commission's Circular Economy package (COM (2014) 398), which states it will encourage the cascading principle for the sustainable use of biomass. The EU Forest Strategy document (COM (2013 659) also determines that wood be used in the order of the following priority: wood-based products, extension of service life, re-use, recycling, bioenergy and disposal.

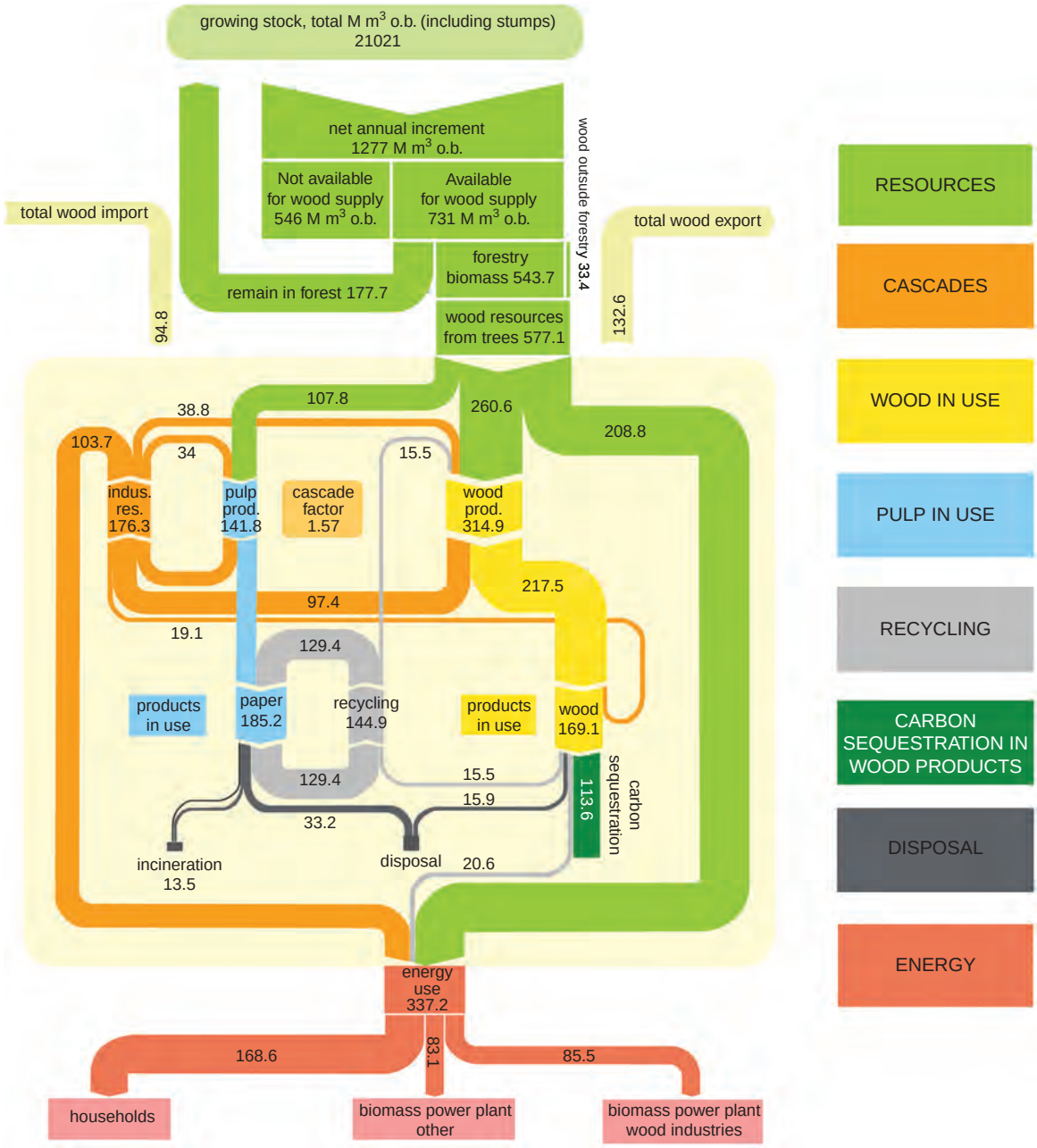


Figure 1.2 Overview of the use of wood in the EU. Source: redrawn from Mantau (2012). Values are in cubic metres of solid wood equivalents.

The main current uses of forest products and services can be divided into several categories, as shown in Figure 1.2, where the flow starts with the harvest from the growing stock, proceeds through processing to main products of saw wood and paper, with a substantial flow also to bioenergy. Overall, European wood is used in almost equal proportions (40%) for energy and products. The remaining 20% is used for pulp.

1.2.1 Use of wood for the production of goods

Traditional EU forest industries are based on pulp (paper, board) and wood products (saw wood, wood-based panels, engineered products). These traditional markets (especially in printing paper) have been declining through global competition, although recently this trend may have stabilised or even reversed. Emerging new forest industries are seen in some Member States supplying the 'bioeconomy', where resources such as lignocellulose in timber are used as feedstocks for chemicals, materials and biofuels. Future prospects for a cost-effective bioeconomy realising its full potential depend on the technological development of biorefineries (Box 3) and an integrated approach for the co-production of value-added products such as biomaterials, biochemicals, bioplastics, food and feed at the same time as bioenergy (including liquid biofuels, biogas, and biomass-generated heat and/or electricity).

Box 3 Biorefining

Biorefining is defined by the International Energy Agency (IEA, 2016) as the sustainable processing of biomass into a range of bio-based products (food, feed, chemicals and materials) and bioenergy (biofuels, power and/or heat). The purpose is to use the raw material in the wood as a chemical feedstock to produce high value chemicals (for example fine chemicals, pharmaceuticals, polymers) and secondary energy carriers (transport fuels such as bioethanol, biogas). Outputs are thus considerably higher up the value chain than just using the biomass for generating heat and/or electricity.

Major chemical components of woody biomass include lignin and sugars, and a range of biological, chemical, physical and thermal processes can be applied to produce biochemicals and fuels. Typical processes include fermentation, biocatalysis, gasification and pyrolysis. Major product streams depend on the chosen biorefining platform and the respective technologies but may include bioethanol, biogas (methane), biochemicals, bioplastics and foodstuffs. Potential industries to which biorefinery products can contribute include the food, electronic, medical and clothing industries. In general, both energy-driven and product-driven biorefineries can be distinguished.

The concept of the biorefinery is still in early stages and has attracted government support for innovation in some countries. As one example, Sweden's Domsjö Development area biorefinery produces several products with applications in viscose production, chemicals, fuels, paints and construction materials. The Swedish Government is supporting the development of an innovation cluster to develop the technical and economic viability of a range of biorefining processes. In Finland, biorefining to produce bio-liquid and biogas transport fuels constitutes a significant part of the national 2016 Energy and Climate Policy (Box 7 in Chapter 5).

A key requirement for any biorefinery development is a large supply of biomass from nearby areas to supply the necessary feedstock, which can conflict with other objectives (for example biodiversity or carbon storage targets). Furthermore, to ensure biorefining contributes to reducing atmospheric carbon dioxide levels, biomass-based products should substitute for existing oil-based production; and ultimately replace some petrochemical refineries (De Jong and Jungmeier, 2015).

1.2.2 Use of wood for bioenergy (substituting for fossil fuels)

Biomass has been widely promoted as a source of 'renewable' energy, and most EU Member States have put in place incentives to encourage its use as a substitute for fossil fuels to generate electricity and/or heat. Underlying this is the EU's commitment to decarbonisation of the energy sector, which requires a switch from fossil fuels to low-carbon renewable sources of energy. More specifically, EU Member States have made binding commitments to provide 20% of their energy from renewable sources by 2020 and a collective commitment to provide at least 27% by 2030. Biomass is currently a major component of the strategy to meet these 2020 and 2030 targets, and over 50% of 'renewable' energy in the EU currently originates from biomass. Some 40% of the annual harvest from EU forests is ultimately (as by-products or post-consumer waste) used for bioenergy (Figure 1.2). Current expectations are that biomass will continue to play an important role in meeting EU energy and climate targets, with forests as a principal contributor. Issues associated with forest biomass use for bioenergy and electricity generation are further discussed in Chapter 4.

1.2.3 Use of forests in climate change mitigation by removing carbon from the atmosphere

The basic role of forests as a sink and source of carbon dioxide are summarised in Box 4. Forests contribute to the global atmospheric carbon dioxide concentration by both sequestering and emitting greenhouse gases (GHG). Global anthropogenic (human-induced) emissions amounted to about 50 gigatonnes of CO_2-equivalent (Gt CO_2e)[6] in 2010, approximately one-quarter (12 Gt CO_2e) of which originated from agriculture and forests. Current initiatives to reduce emissions globally are insufficient to prevent global temperatures from increasing by more than 2 °C above pre-industrial levels (Rogelji *et al.*, 2016), and the emission mitigation actions proposed in the 2015 United Nations Climate Change Conference in Paris (also known as twenty-first session of the Conference of the Parties, COP21) Intended Nationally Determined Contributions still leave a significant emissions gap. It is thus important to determine to what extent forests could be used to reduce this gap.

Climate change mitigation via forests requires three interlinked actions: first, increasing the share of wood-based products with long lifetimes (for example building materials) and the use of wood as a substitute for fossil fuels *where this delivers a net benefit to the atmospheric carbon budget*; second, increasing the GHG-efficiency of the production of wood-based products; and third, increasing the rate of carbon storage and the size of carbon stocks in forests and forested land. The Intergovernmental Panel on Climate Change (IPCC) estimated the potential from the forestry sector globally as 2.7 Gt CO_2e per year (IPCC, 2007), while the EU has suggested that GHG mitigation and adaptation in the (EU) land sector could abate between 0.32 and 0.35 Gt CO_2e per year by 2030 (JRC, 2016). This will be discussed further in Chapter 2.

[6] Units in assessing global warming effects can be based on carbon emissions (tonnes of carbon: t C), carbon dioxide (tonnes of CO_2: t CO_2) or also include emissions of other GHG, making allowance for their different global warming potentials (tonnes of CO_2 equivalent: t CO_2e).

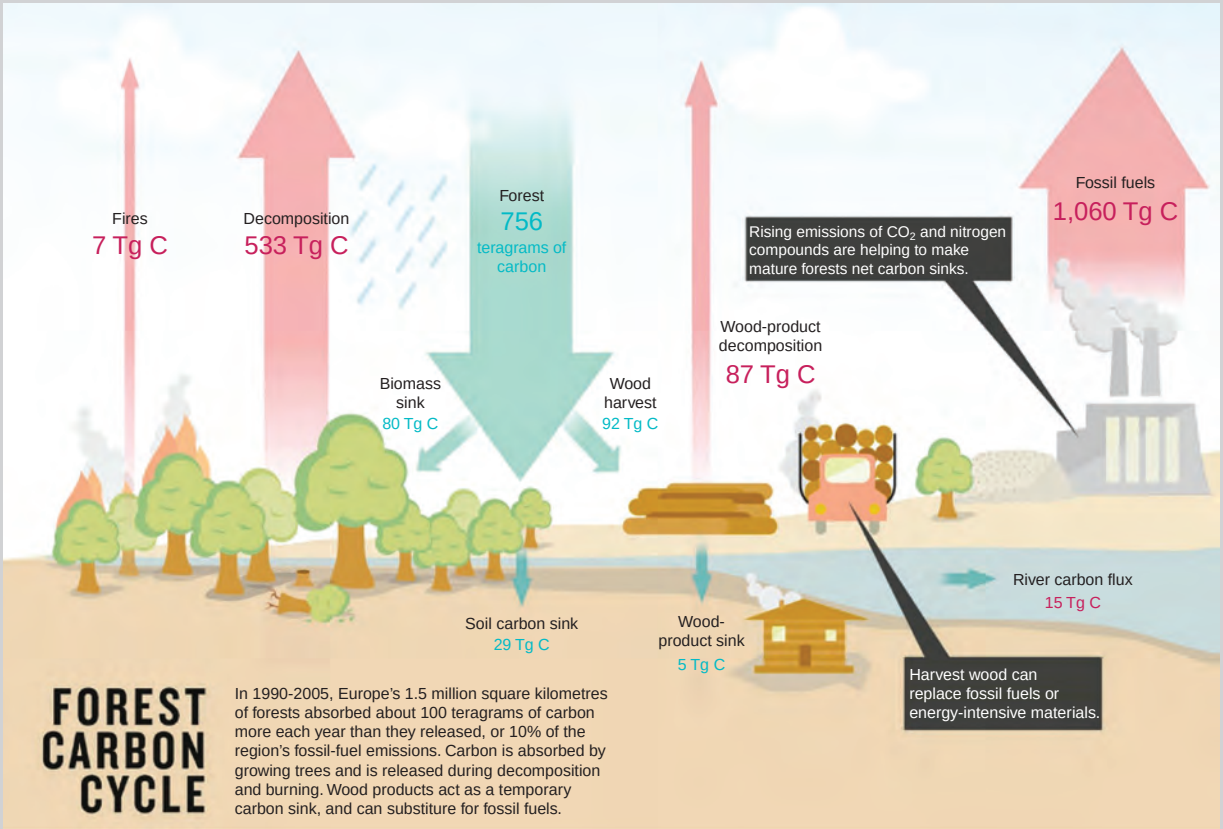
Box 4 Forests as sinks and sources of carbon dioxide

Forests perform an important function by removing carbon dioxide from the atmosphere through photosynthesis. Globally, land ecosystems (including forests, agricultural lands, etc.) remove about 30% (9.5 ± 2.9 Gt CO_2/yr) of anthropogenic carbon dioxide emissions, demonstrating the significance of forests' role in mitigating the accumulation of carbon dioxide in the atmosphere (Houghton *et al.*, 2012; Giglio *et al.*, 2013; Le Quéré *et al.*, 2015). The net forest carbon sink is the balance between carbon inputs (photosynthesis) and carbon outputs. In the case of a net sink, the carbon inputs exceed the outputs, resulting in storage of carbon (1 m^3 of wood stores ≈ 0.92 t CO_2). The outputs are determined by three main pathways: respiration (50%; Luyssaert *et al.*, 2007), decomposition (36%; Luyssaert *et al.*, 2010), and removal of the carbon from the site through harvest, fire, run-off and leaching (7%). Globally, terrestrial carbon uptake has been increasing over recent decades, one significant reason being the combined effects of rising carbon dioxide concentrations on photosynthesis (the carbon dioxide fertilisation effect) and, in the past decade, a slowdown of global respiration in response to warming (Keenan *et al.*, 2016). At present in the EU, the net forest carbon sink (i.e. the rate of carbon storage increase) amounts to 7% of the carbon input to the ecosystem (Luyssaert *et al.*, 2010) and is stored in the soil and in below- and above-ground biomass. The ratio between above- and below-ground storage is important for the longevity of the carbon sink and varies as a function of nutrient availability and management (Vicca *et al.*, 2012; Fernández-Martinez *et al.*, 2014; Campioli *et al.*, 2015). In practice, managed forests on nutrient-rich sites offer the highest carbon sink.

Forest carbon dynamics are characterised by long periods of slow carbon uptake, interrupted by short periods of rapid and large carbon releases during disturbances or harvest. Depending on the stage of stand development, individual stands are either carbon sources or carbon sinks. For most stages of stand development, stands are carbon sinks. While individual stands in a forest may be either sources or sinks, the forest landscape carbon balance is determined by the sum of the net balance of all stands. The theoretical maximum carbon storage (saturation) in a forested landscape is attained when all stands are in an old-growth state, but this rarely occurs since natural or human disturbances maintain stands of various ages within the forest.

Even in very old forests, ecosystem carbon storage will still continue to increase slowly with accumulations; mostly in dead organic matter and soil carbon pools. In the years following major disturbances, the losses from decay of residual dead organic matter exceed the carbon uptake through regrowth. Even though old forests often have a lower rate of carbon absorption than young forests, they store a larger amount of carbon over their whole life cycle (Schulman, 1954; Luyssaert *et al.*, 2008; Hudiburg *et al.*, 2009; Bugmann and Bigler, 2011; Bigler and Veblen, 2009).

The annual increment of wood in the forests of the 28 EU Member States amounts to 720 million m^3 (Forest Europe, 2015). This translates into a gross uptake of about 756 million tonnes (teragrams (Tg), 10^{12} g) of carbon annually (Luyssaert *et al.*, 2010). After accounting for harvest and losses from decomposition, 100 million tonnes of carbon is sequestered annually; this represents the carbon that is removed from the atmosphere and for Europe is equivalent to about 10% of its fossil fuel emissions (Nabuurs *et al.*, 2003, 2015; Luyssaert *et al.*, 2010; Tupek *et al.*, 2010). A summary of these flows is shown in the figure below (Bellassen and Luyssaert, 2014).



Forest and soil carbon stocks and flows in Europe.

1.2.4 Other forest-based ecosystem services: biodiversity conservation, recreation, etc.

In several countries, forest ecosystems provide mushrooms, berries and other benefits to local people; 65 million EU citizens collect wild food (Schulp *et al.*, 2014). Biodiversity conservation, i.e. the combined goal of protecting habitat, species and genetic diversity, is an important function of forested land, and intimately linked to many other functions that forests deliver. A large part of the European fauna and flora depends in full or in part on forests, and trees and forests are part of our cultural and historical heritage.

Biodiversity in forests is in decline[7] and very few biodiversity 'hotspots' such as old-growth forests remain in Europe. Climate change and forest management are major threats for conservation areas and biodiversity (Araújo *et al.*, 2011), with 58–63% of European plant and terrestrial vertebrate species projected under climate change scenarios to lose suitable climate niches (even in protected areas) by 2080. The EU biodiversity strategy to 2020 includes among its targets an increased contribution of forestry to biodiversity. The adoption of genuinely SFM is expected in public forests, and to be encouraged in private holdings via subsidies to reward actions towards biodiversity conservation objectives.

1.3 EU forest policies and their relationships to international agreements

In the EU, forest policies remain the competence of Member States within various frameworks of ownership rights and national and regional laws and regulations. Increasing attention has been paid to the sustainability of forestry management under accreditation schemes such as the Forest Stewardship Council (FSC) and the Programme for the Endorsement of Forest Certification (PEFC). The EU Forest strategy in 2013 aimed also to integrate forest use with climate change and agricultural policies, although implementation remains the responsibility of Member States (EC, 2013). This dependency on national competencies is in contrast to the increasingly global scale of related policy issues such as climate change mitigation and biodiversity conservation, and makes achieving EU level synergies challenging.

The EU already recognises the interaction of different policy objectives within the common theme of 'forests': in regional wealth creation and employment, natural resources and raw materials, nature conservation and biodiversity, climate change and energy policy and agriculture. Consequently, the many Directorates-General of the European Commission, which are responsible for policies that are linked to forests, face a significant challenge to ensure a systematic approach, to avoid conflicts and to enhance sustainability and synergies between different policy domains.[8]

In addition to national and EU level policies, the UN Conventions on climate change and on biological diversity have a direct link with several EU activities; for instance the following:

- *Climate change*: UNFCCC; 2009 Renewable Energy Directive (RED); 2011 Low Carbon Economy Roadmap; 2013 Decision on GHG emissions and removals; 2030 Climate and Energy Framework; 2016 Ratification of the Paris Agreement; inclusion of greenhouse gas emissions and removals from LULUCF into the 2030 Climate and Energy Framework (20 July 2016); November 2016 package on 'Clean Energy for All Europeans'.

- *Biodiversity*: United Nations Convention on Biological Diversity; Birds Directive 1979; Habitats Directive 1992; Alien Species Regulation 2014; Biodiversity Strategy 2011-2020; Mid-term review of EU Biodiversity strategy (Dec 2015).

[7] According to EEA (2016), only 26% of forest species and 15% of forest habitats of European interest, as listed in the Habitats Directive, were in 'favourable conservation status' in 2007–2012, and 27% of mammals, 10% of reptiles and 8% of amphibians linked to forest ecosystems are considered to be under threat of extinction within the EU.

[8] Although there is no common forest policy at EU level, dialogue and cooperation on forest policies has existed since 1990 within Forest Europe (The Ministerial Conference on the Protection of Forests in Europe) to develop common strategies on how to protect and sustainably manage forests at the European scale.

2 Forests and climate change

As the international community has moved within the UNFCCC to address global warming and climate change, the role of forests has received much scrutiny. Most recently, the 2015 agreement at UNFCCC COP21 (Paris Agreement) acknowledges the need for SFM and the enhancement of forest carbon stocks. This in turn requires those who are responsible for defining and implementing forest management practices to have a detailed knowledge of how forests and their management may contribute to carbon capture and storage, to GHG emissions or other impacts. The radiative forcing factors[9] that are particularly relevant to forestry are shown in Figure 2.1, where it can be seen that the impacts of forests on global average temperatures can be positive or negative and are not all fully accounted for in current policies.

2.1 Climate change and impacts on European forests' vitality

The effects of climate change on forests are very different in the various parts of Europe (EEA, 2017). They are already visible in Mediterranean and Alpine areas through an increase in tree mortality (Bréda *et al.*, 2006; Dobbertin *et al.*, 2007) and species shifts (Hlásny *et al.*, 2011; Rigling *et al.*, 2013). In contrast, in the continental and boreal zones of Central and Northern Europe, forest growth rates have increased owing to the elevated atmospheric carbon dioxide concentrations increasing the photosynthesis rate of plants, as well as longer growing seasons and nitrogen deposition (Lindner *et al.*, 2014; Pretzsch *et al.*, 2014; Donohue *et al.* 2013; Zhu *et al.* 2016). In combination with stable harvest rates, these changing environmental conditions have led to increased carbon stocks in these areas.

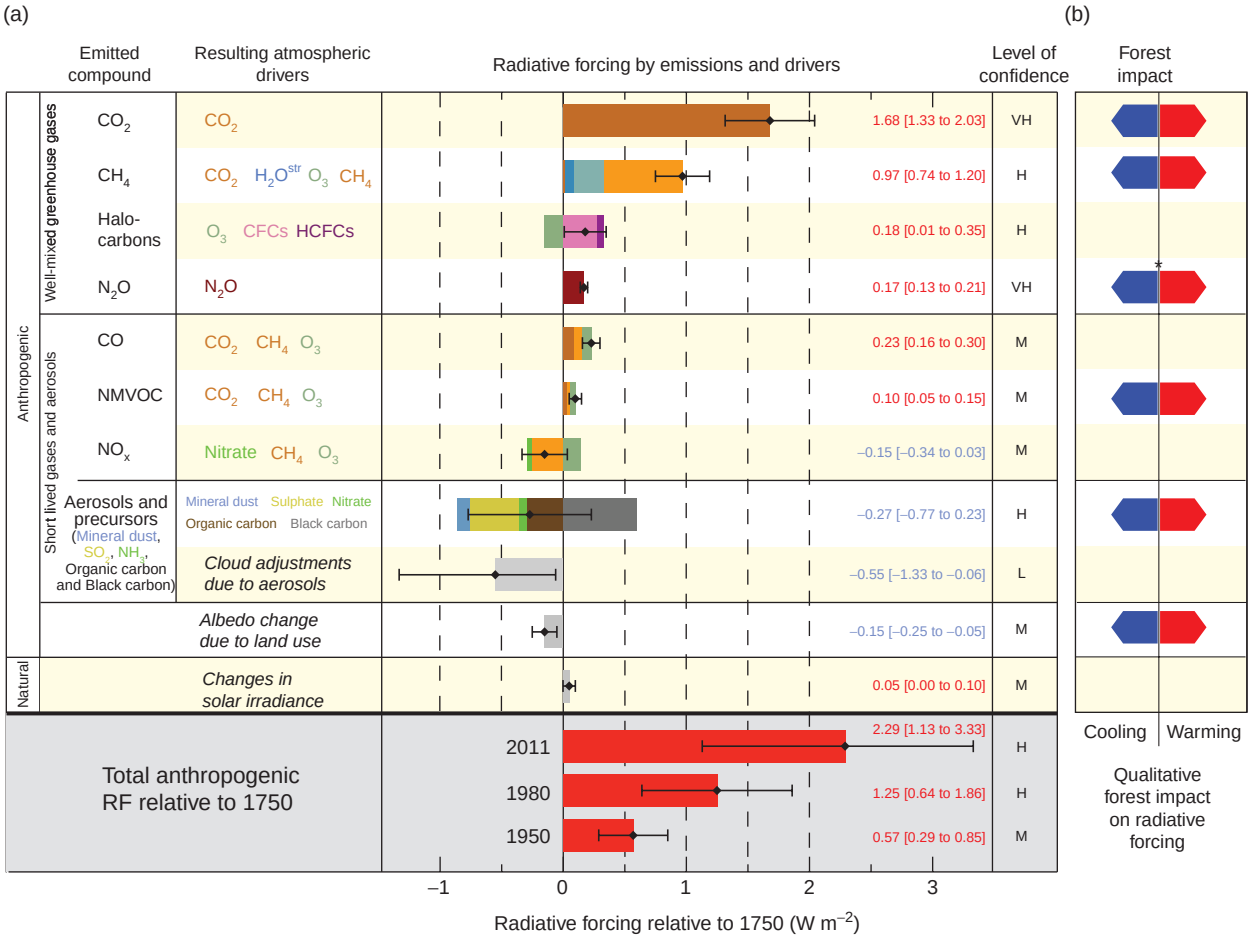


Figure 2.1 The relation between radiative forcing (RF) drivers, the influence of global forests and whether this is accounted for in current EU policies (adapted from Figure SPM.5 in IPCC (2013)). (A) The role of atmospheric components in warming or cooling. Values show global radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change. Negative/blue values indicate cooling; positive/red, warming. Level of confidence: VH, very high; H, high; M, medium; L, low. NMVOC, non-methane hydrocarbons. (B) The qualitative impact of forests on atmospheric components that have an influence on warming. Note that the impact of forests can be either cooling or warming the climate, depending on the management options chosen.

[9] Radiative forcing is the capacity of a gas or other forcing agent to affect the energy balance from the sun.

In general, forest growth is projected to continue to increase in Northern Europe and to decrease in Southern Europe, but with substantial regional variations. For example, some cold-adapted, coniferous trees are estimated to lose large fractions of their ranges to more drought-adapted broadleaf species. Further, under future climate scenarios, increased mortality may lead to large areas where forests will be replaced by other vegetation (Allen *et al.*, 2010), and if current warming trends remain unabated, scenarios to 2100 suggest the likelihood of major shifts north in the current forest types (Hanewinkel *et al.*, 2013) as a result of changes in temperature and precipitation, with severe economic consequences.

Extreme storms cause significant damage to Central and Western European forests (Schelhaas *et al.*, 2003; Lindroth *et al.*, 2009; Gardiner *et al.*, 2010), and since the 1990s have damaged hundreds of millions of cubic metres of timber (Usbeck *et al.*, 2010). Storm damage (the combination of strong winds, heavy rains and extended growing seasons for deciduous trees) not only affects timber production, but simultaneously disrupts carbon sequestration and releases stored carbon to the atmosphere (Lindroth *et al.*, 2009). In addition, it often leads to follow-up damage by insects that may spread to other forest areas. At the same time, the damaged wood is an important resource for the many dead-wood-dependent species, and storm damage can thus have both negative and positive effects. Increases in extreme weather (EASAC, 2013) require forestry management strategies to adapt in areas affected by heavy winter storms. In Mediterranean areas, climate change is contributing to drought stress, which may lead to an increase in wildfires as well as infestations by insects.

Overall rates of damage are shown in Figure 2.2, where it can be seen that damage from wind, bark beetles and wildfires have increased between 1971 and 2010, although the extent of damage is still only a few per cent of the EU forest area. Using an ensemble of climate change scenarios, further increases are predicted of 0.91 million m^3 of timber per year until 2030.

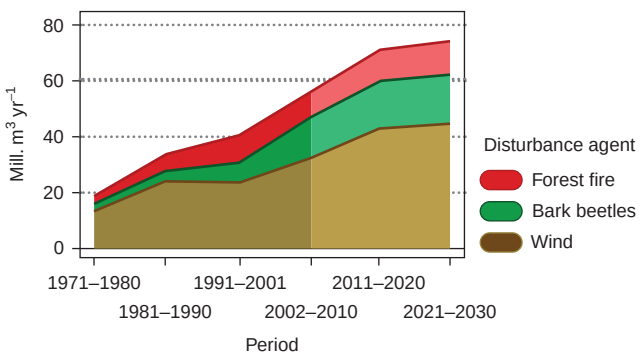


Figure 2.2 Recent trends and future forecasts for forest damage in the EU (Seidl et al., 2014).

This increasing trend has been attributed to both climate change and changes in forest structure through management, so that adaptive management (see Chapter 5) could partly mitigate forest damage with a stronger focus on disturbance risk and resilience (Seidl *et al.*, 2014).

Designing forest regeneration schemes to take into account local conditions is an important tool for storm damage mitigation. A shortening of rotation times may in some regions increase resilience towards storm and insect damages, as tall evergreen trees on shallow soils are often more vulnerable—especially in an even-aged forest with homogenous stand structure (Meilby *et al.*, 2001; Gardiner *et al.*, 2010; Hale *et al.*, 2015; Schmidt *et al.*, 2010). However, there are trade-offs with carbon storage and biodiversity, which can be increased by lengthening the rotation period (Yousefpour and Hanewinkel, 2009), as discussed further in section 2.2 and Chapter 3.

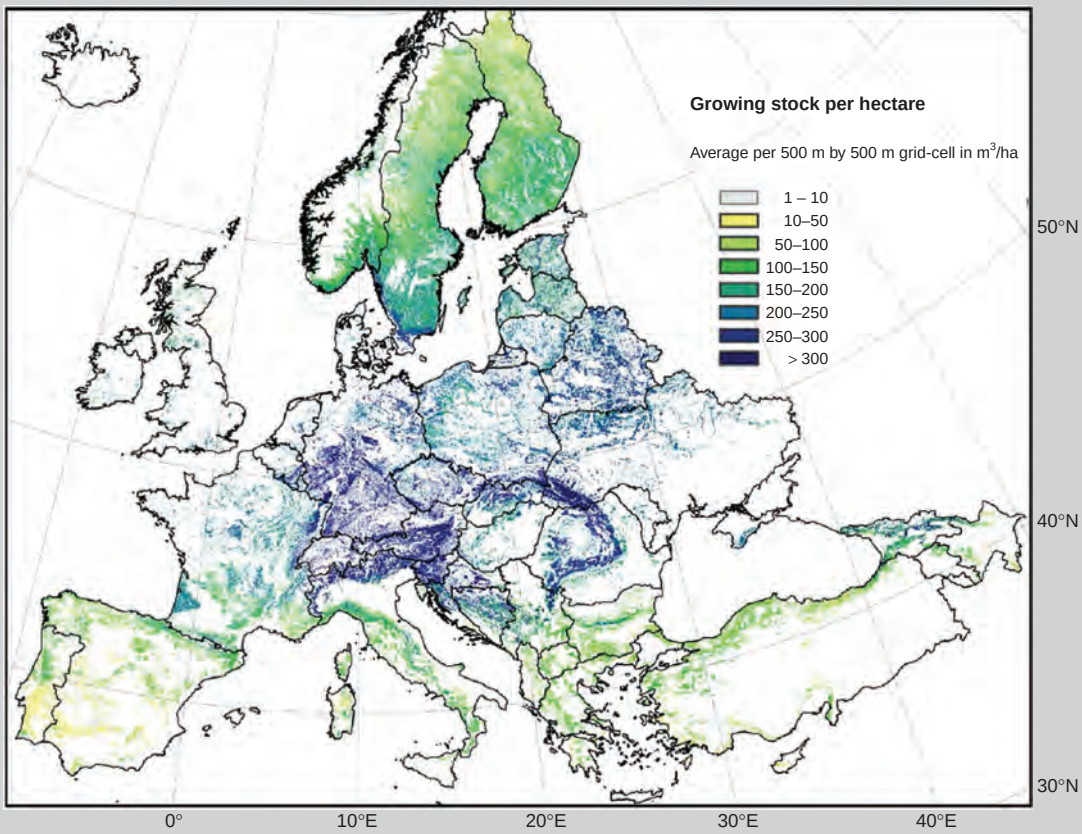
Forest vitality and resilience are fundamentally linked to the genetic diversity of forest stands (Koskela and Lefèvre, 2013). Tree populations with a high level of genetic diversity have a better chance of defending themselves against pests (Müller-Starck, 1995). In this context, genetic diversity not only increases the likelihood that the population will persist, it also forms the basis for adaptation of species over the longer term. Monocultures developed from a narrow genetic basis are likely to be more susceptible to pests and diseases—especially if they are based on clones. Species richness is also important for the resilience of the ecosystem as a whole (Fares *et al.*, 2015). Since 30% of forest stands in Europe are dominated by one tree species (mainly conifers), forest management options ranging from mixed native species plantations to continuous cover forestry offer the potential to increase resilience by increasing species diversity (see also Chapter 3). For longer-term climate change scenarios (Hanewinkel *et al.*, 2013) of major declines in some economically important species such as Norway spruce and European beech, potential adaptation measures include new, better drought- and heat-adapted species or varieties, assisted migration of tree species to areas where they may be better adapted, traditional breeding or genetic modification, and gene conservation. However, potential harmful effects of such management tools on biodiversity and other ecosystem services need to be assessed before adoption.

2.2 Forests as sinks and stocks of carbon

A summary of current trends in the amounts of carbon stored in Europe's forests is given in Box 5. Clearly, enhancing the role of forests as carbon sinks requires forests to be resilient to climate-change-related impacts that could release the sequestered carbon back into the atmosphere. Forest management approaches and

Box 5 Carbon stocks and forest carbon sinks

As described in Box 4, forests remove carbon from the atmosphere and store it in biomass and soil, thereby contributing to climate change mitigation. Carbon stocks across Europe vary widely, both locally and across countries, and are determined by climate, soils, tree species, management history, etc. (see figure below).



Growing stock of stemwood in cubic metres per hectare for a 500-m × 500-m resolution of European forests (Gallaun et al., 2010).

Harvesting intensities vary a lot between and within Member States (Barredo *et al.*, 2012), and forest carbon storage is currently increasing over large parts of Europe (Nabuurs *et al.*, 2003) owing to harvesting less than the annual wood increment (Forest Europe, 2015), carbon dioxide fertilisation (Norby *et al.*, 2005, Donohue *et al.*, 2013, Keenan *et al.*, 2016, Zhu *et al.*, 2016), warming (Myneni *et al.*, 1997; Luo, 2007), increasing stand density by suppressing fire and abandoning grazing (Rautiainen *et al.*, 2011), nitrogen deposition from burning fossil fuels and from agricultural fertiliser use (Magnani *et al.*, 2007), decreasing nutrient harvest by abandoning litter raking and grazing (Spiecker *et al.*, 1996; Gimmi *et al.*, 2013), large-scale afforestation (Nilsson and Schopfhauser, 1995) and natural succession following land abandonment (Olofsson *et al.*, 2011; Fuchs *et al.*, 2015; Kuemmerle *et al.*, 2015).

Because conditions in different parts of Europe vary and interactions are not fully understood (Hyvönen *et al.*, 2007), it is unclear for how long the carbon sink in EU forests will continue to increase, especially since historical records show carbon storage in Europe to have been significantly lower (Kaplan *et al.*, 2012). In this context, Nabuurs *et al.* (2013) have reported the first signs of carbon sink saturation in European forest biomass. Moreover, growth in some species (especially beech) has been reversed in recent years (Kint *et al.*, 2012). Nevertheless, there may be potential for increasing the carbon sinks and stocks in currently managed forests by changing management practices to encourage higher levels of standing biomass (at least in some regions).

planning are particularly important for controlling the carbon balance as the climate changes (Garcia-Gonzalo *et al.*, 2007; Mäkipää *et al.*, 2011, 2015) and for reducing the risk of large-scale forest dieback.

Owing to socio-economic changes in rural areas, some agricultural lands in Europe have been abandoned, following which afforestation often occurs either through natural succession or deliberately.[10] Afforestation of degraded (or marginal) lands has also been suggested as a means of increasing forest carbon stocks, and studies indicate that the global effects of afforestation on GHG-management could be substantial in terms of additional carbon dioxide sequestration

[10] Planned or deliberate afforestation was estimated at 1.5 million hectares (Mha) whereas successional afforestation resulted in 11.4 Mha of new forests between 1990 and 2015 alone (UNECE/FAO, 2011; Forest Europe, 2015).

(Nabuurs *et al.*, 2007), although it may take several decades before the biomass stocks in vegetation and soils of the newly planted forests exceed those present before the land was converted (Nabuurs *et al.*, 2009).

However, land taken for afforestation (planned or successional) could conflict with other policy objectives such as food production, conserving biodiversity and sustaining a minimal river discharge (Jackson *et al.*, 2005). The different climatic conditions in EU countries and balancing demands for land between forests lands, grasslands and wetlands may also affect the potential for afforestation. Indeed, what are sometimes regarded as marginal lands can be grasslands of high nature value (Burrascano *et al.*, 2016), which are considered to be important for biodiversity conservation and contain high soil carbon pools. Such afforestation may thus decrease biodiversity as well as involving long delays before a net reduction in carbon emissions is achieved. Taking these factors into account, it has been estimated that some 15 million hectares of abandoned farmland in the EU could be available for planned afforestation up to 2030 (Keenleyside and Tucker, 2010).

Nabuurs *et al.* (2015) have proposed the concept of 'climate smart forestry' policy, which would aim to increase forest productivity and incomes by adapting and building resilience to climate change, and by reducing and/or removing GHG emissions. Components would include tax incentives for regeneration with more resilient trees, using wood in place of more carbon-intensive products (for example steel or concrete), carbon dioxide credits and other payments for ecosystem services. Through such policies, it was estimated that EU forests, their wood supply chain and energy contributions could compensate for up to 20% of total EU fossil fuels emissions (Nabuurs *et al.*, 2015). However, the overall climate impacts of climate smart forestry have not yet been fully evaluated, nor the compatibility between shifting to climate-resilient species and market demands.

2.3 Accounting for all climate impacts of forestry

The climate effect of forest management via the carbon balance is supplemented by the biophysical effects (Pielke *et al.*, 2002; Jackson *et al.*, 2008) of albedo, forest structure, evapo-transpiration, and the release of volatile organic compounds and microbes from plant surfaces capable of forming aerosols and subsequently clouds (Ellison *et al.*, 2017). In addition, other GHG (such as methane and nitrous oxide from wetlands and forest with wet soils) may contribute significantly to climate warming (Figure 2.1), although management options such as drainage and wetlands management can reduce their contributions locally. In tropical regions, the GHG and biophysical effects of a forest tend to work together to cool the land surface (Baidya and Avissa, 2002; Jackson *et al.*, 2008; O'Halloran *et al.*, 2012). However, in areas with substantial snow cover, the GHG sequestering effect of afforestation is easily offset by the biophysical effects whereby reduced snow cover reduces reflection of solar radiation back to space (Randerson *et al.*, 2006; Jackson *et al.*, 2008; Lee *et al.*, 2011). The transitional latitude where afforestation and forest management choices contribute to climate cooling rather than to climate warming is located in the temperate zone, but its exact location is subject to ongoing scientific debate (Li *et al.*, 2015; Alkama and Cescatti, 2016). The transitional latitude falls within the European domain, so cases where biophysical effects either strengthen or counteract GHG effects can be expected to occur. Indeed, Naudts *et al.* (2016) showed that the overall effects of European forest management on climate between 1750 and 2010 were a small warming rather than the commonly assumed substantial cooling.

Biophysical effects can, in some circumstances, be of similar magnitude to the net effects of changing the carbon balance through afforestation or deforestation (Luyssaert *et al.*, 2014); warming effects through albedo changes may be offset by the potential cooling effects of forest-originating aerosols (Kulmala *et al.*, 2014, Teuling *et al.*, 2017). Ellison *et al.* (2017) reviewed the effects of trees and forests as prime regulators within the water, energy and carbon cycles and suggest they should be managed to increase their contribution to climate cooling through hydrological mechanisms and not just from a carbon-centric perspective. The accumulating evidence thus suggests that ignoring biophysical interactions – as is currently the case in the Kyoto Protocol and the Paris Agreement – could result in mitigation projects that provide little climate benefit or, in the worst case, are counter-productive (Marland *et al.*, 2003; Jackson *et al.*, 2008; Naudts *et al.*, 2016).

While accounting for biophysical effects is difficult, current evidence suggests that in the boreal and temperate zones, the net effects of deciduous species are likely to lead to cooling, whereas the net effects of evergreen species are more difficult to quantify (Zhao and Jackson, 2014; Matthies and Valsta, 2016). Preferential use of mixed evergreen–deciduous stands (Northern EU countries) or deciduous stands (Central Europe) could be a reasonable strategy for climate change mitigation based on current evidence related to biophysical effects.

3 Forests and biodiversity

3.1 Forest biodiversity and ecosystems services

Protecting biodiversity is an aim in itself under the CBD and EU Biodiversity Strategy but is also highly significant in the context of ecosystem functions and the associated benefits people obtain from ecosystems (Díaz *et al.*, 2015a). Generally, three categories of ecosystem services are distinguished: *provisioning services* provide food, fuel, genetic resources, water and energy; *regulating and maintenance services* secure climate regulation, protection against natural hazards such as floods and erosion, pollination, etc.; and *cultural services* maintain recreation activities, aesthetic, religious and spiritual experiences (Haines-Young and Potschin, 2013). Biodiversity, as one of the most important ecosystem condition indicators, enables ecosystems to provide services. Without the maintenance of good ecological condition and biodiversity the preservation of services cannot be achieved.

In the case of forests, FAO (1997) includes the following examples of ecosystem services.

- Regulation of water regimes by intercepting rainfall and regulating its flow through the hydrological system.
- Maintenance of soil quality and the provision of organic materials through leaf and branch fall.
- Limiting erosion and protecting soil from the direct impact of rainfall.
- Modulating climate.
- Providing the raw material for a variety of industries including timber, processed wood and paper, energy and fruits/nuts.
- Products used by rural agricultural communities (fuel and fodder, grazing, game, fruits, building materials, medicines and herbs).
- A key component of biodiversity both in themselves and as a habitat for other species.
- Socio-cultural services—many people have strong cultural and spiritual attachments to forests. Many local people understand how to conserve and use forest resources.
- Scenic and landscape services and values- aesthetics and beauty as components of services of forests—both from the perspective of tourism and of importance to residents.

Several studies underline the critical role of biodiversity in the supply of ecosystem services (Hooper *et al.*, 2005; Balvanera *et al.*, 2006; Luck *et al.*, 2009; TEEB, 2010; Bastian, 2013;). A decline in biodiversity threatens the ability of both managed and natural ecosystems to adapt to changing conditions and hampers the provisioning of ecosystem services (Bellard *et al.*, 2012; Díaz *et al.*, 2015a; 2015b). A recent meta-analysis (Liang *et al.*, 2016) reviewed global forest data from more than 770,000 sample plots in 44 countries and found a positive and consistent relationship between tree diversity and ecosystem productivity at landscape, country and eco-region scales. According to that study, an average 10% loss in tree species diversity leads to a 3% loss in productivity, which equates to a global economic value of US$166 billion to US$490 billion per year—over five times the expenditures on global conservation.

Forests are a critical habitat for many species and a major contributor to biodiversity at both global and European levels. At the global level, biodiversity is in decline, with the Living Planet Index (a measure of the state of the world's biological diversity of vertebrates) showing a decline of 52% between 1970 and 2010 (WWF, 2016). The European Red Lists identify the species that are threatened with extinction at the pan-European and EU level[11]: 15% of Europe's 231 mammal species are threatened, and a further 9% are close to threatened status, with habitat loss and degradation being the greatest drivers of decline (Temple and Terry, 2007). Nineteen per cent of Europe's 488 bird species are threatened or near threatened, with biological resource use (including forestry) and agriculture and aquaculture being the main drivers of endangerment (Gregory *et al.*, 2007; Lehikoinen and Virkkala, 2017). Of the plants that have been assessed for the whole of Europe, 25% are threatened with extinction (Bilz *et al.*, 2011). Red Lists of forest species include saproxylic beetles where 14% (57 species) are threatened in EU countries and a further 13% considered near threatened (Nieto and Alexander, 2010). Furthermore, 14% of habitats and 13% of species of European interest are assessed as being under pressure because of climate change (EEA, 2017), and habitats threatened by climate change are projected to more than double in the near future.

Forest Europe (2010) assessed the implementation of the CBD and proposed pan-European Indicators for SFM including nine biodiversity indicators (tree species composition; regeneration; naturalness; introduced tree species; deadwood; genetic resources; landscape

[11] http://ec.europa.eu/environment/nature/conservation/species/redlist/

pattern; threatened forest species; protected forests). Guidance is already provided in some Member States on enhancing biodiversity through SFM. For instance, UK Forestry Standard Guidelines on biodiversity include consideration in SFM of priority habitats and priority spaces; native woodlands; landscape ecology; ecological processes; tree and shrub species selection; veteran trees and deadwood; open scrub and edge habitats; riparian zones; habitat creation and restoration; dealing with invasive species; and the use of grazing and browsing (Forestry Commission, 2011).

3.2 The importance of forest structural elements, old-growth forests, and forest continuity for biodiversity

The forests in the EU are diverse and complex, and biodiversity conservation in forests differs between regions. Here we concentrate on a few central issues for EU-wide policy, which also coincide with megatrends driving global biodiversity decline—particularly the reduction of habitats and the deterioration or degradation of habitat conditions.

Conventional logging using uniform shelterwood or clear-cutting systems is practised across Europe and leads often to homogenous stands with reduced quantities of standing deadwood and logs, an even-aged structure, and a lack of rare woody species and large veteran trees (Woodcock *et al.*, 2015). Some recent efforts have emerged to introduce novel techniques such as retention forestry (Gustafsson *et al.*, 2012) and to adjust clear-cutting and shelterwood management, but forest management and utilisation remain key factors limiting the biodiversity of Europe's forests (EEA, 2008, 2016). Moreover, pressures to extract more wood from forests typically lead to reduced population sizes of the species dependent on forest cover continuity, deadwood and large trees and, in the worst case, local extinctions (Brunet *et al.*, 2010; Paillet *et al.*, 2010).

Except for a few habitats dominated naturally by one or two tree species, natural forest ecosystems usually contain several woody species. Such multi-species forest habitats provide higher levels of ecosystem services (productivity and biomass included) than forests with one or a few tree species, as no single tree species is able to provide all ecosystem services (Balvanera *et al.*, 2013; Gamfeldt *et al.*, 2013; Tilman *et al.*, 2014). In spite of this, mainly as a consequence of maximising volume yield in timber production, one-third of European forest stands are dominated by only one tree species, and only 20% harbour more than three species (Nabuurs *et al.*, 2015).

The most important structural elements for biodiversity in forests are standing and lying dead trees, hollow trees, rare woody species and large veteran trees (Bauhus *et al.*, 2009; Brunet *et al.*, 2010); large living trees and high amounts of deadwood form the basis for a significant part of forest biodiversity (Peterken, 1996; Larsson, 2001; Stokland, 2001; Bobiec, 2002; Bartha *et al.*, 2006; Burrascano *et al.*, 2013). Large trees that provide microhabitats such as cracks, bark injuries, crown dead wood (so-called habitat trees) are essential for many Natura 2000 species including epiphytes and several birds of prey. Standing dead trees or trees weakened by fungi provide habitat for almost all cavity-nesting birds, such as woodpeckers, several song birds, and for forest-dwelling bats and mammals (Bobiec, 2005), and a whole range of endangered saproxylic beetles are dependent on these forest elements (Nieto and Alexander, 2010; Müller *et al.*, 2014). The volume of dead wood per hectare has thus become a pan-European indicator for SFM.

One of the most important measures to safeguard forest biodiversity is thus the protection of remaining old-growth and virgin forests (a *land sparing concept*). Old-growth stands can be managed or unmanaged, but are generally defined as stands with more than 200 years' growth (Peterken, 1996). Virgin forests which have never been significantly influenced by people constitute only 2% of European forests, with the highest proportion in Central-East and South-East Europe (Forest Europe, 2015). Such old-growth and virgin forests are biodiversity hotspots which also provide large long-term carbon storage (Luyssaert *et al.*, 2008). Much of the last remaining natural forests of Europe are located in Romania, but are increasingly being lost (Knorn *et al.*, 2012). In Finland also, the area of forest stands over 160 years of age has decreased by 23.4% during the past 15 years (Kotiaho, 2017).

A second means of enhancing biodiversity is to increase spatial structural elements in managed forests (a *land sharing concept*). Here, the deadwood and habitat trees are critical structural elements; for example, in Finland and many other countries about 25% of all forest species are either directly or indirectly dependent on deadwood (Siitonen, 2001; Paillet *et al.*, 2010). In the UK, approximately 20% of forest-dwelling species depend on dead or decaying wood for all or part of their life cycle (Humphrey and Bailey, 2012). Some countries apply specific forest certification schemes (FSC, PEFC) to improve biodiversity conservation in production forests. However, such measures, while avoiding complete loss of features important for biodiversity, can only moderate the harmful impacts of forestry on biodiversity and not enhance biodiversity. Certification is not therefore sufficient to significantly improve the conservation status in managed forests.

As managed forests cover large areas in Europe, protecting forest biodiversity requires the conflicts between timber production and biodiversity

conservation to be addressed using alternative silvicultural methods such as retention forestry, where the unlogged part of the original stand maintains the continuity of structural and compositional diversity (Gustafsson *et al.*, 2012). Several authors emphasise that special forest structural elements, such as hollow trees, large trees, standing and lying dead trees should be maintained in managed landscape as well (Bauhus *et al.*, 2009; Brunet *et al.*, 2010). The maintenance of forest continuity is critical at stand and landscape scales for the protection of many forest-dwelling species, as their ability to disperse is limited in current fragmented landscapes (see, for example, Nordén *et al.* 2013; Abrego *et al.*, 2015). There are large forest areas in Europe that possess continuity in that they have never been converted to agriculture, and thus have undisturbed soils which can ensure the long-term survival of ancient forest species, and may also serve as sources for dispersal into the surrounding landscape (Hermy and Verheyen, 2007). Ensuring the continuity of forest stands at local and/or landscape scale is an important component of biodiversity protection.

The concept of land sharing versus land sparing originates from the question of how to combine food production and conservation (Green *et al.*, 2005; Phalan *et al.*, 2011; Tscharntke *et al.*, 2012), but can also be applied to the forestry sector (Cote *et al.*, 2010), although it is still under debate (Fischer *et al.*, 2014). With forests, land sharing is centred around integrating biodiversity conservation, and wood and fibre production on the same land. In Europe, it would require management strategies that maintain and/or restore natural levels of biodiversity while simultaneously satisfying the demand for wood and fibre. At the other end of the spectrum, land sparing separates land for wood and fibre production from land for conservation. By using selected species, fertilisation and/or irrigation, high production levels are realised in the managed lands, so that not all forest land available is required to supply the demand for wood and fibre—thus enabling protection of the remaining forest. Because the protected land has no other functions, rewilding some of Europe's forests could even be considered (Navarro and Pereira, 2012). Given that production partly depends on biodiversity (Liang *et al.* 2016), both approaches require careful design and implementation to be effective (Tscharntke *et al.*, 2012; Fischer *et al.*, 2014).

At present, intensive forest management and timber extraction produces little deadwood and often removes even the cutting residues, so that levels of deadwood in managed forests are relatively low at 4–7 m^3 per hectare. In contrast, in virgin and old-growth forests, the volume ranges from approximately 50 m^3 per hectare to more than 200 m^3 per hectare (Siitonen, 2001; Christensen *et al.*, 2005; Vandekerkhove *et al.*, 2009). This substantial reduction in the dead wood available for forest-dwelling species has had, and continues to have, a drastic negative effect on biodiversity. As mentioned above, the amount of deadwood in managed forests is one indicator of a forest's contribution to biodiversity, and allowing the percentage of deadwood to increase to 30% of natural levels (that is, approximately 15–60 m^3 of dead wood per hectare) could help to limit further biodiversity loss (Müller and Bütler, 2010; Hanski, 2011, 2013). Natural disturbances such as forest fires and windthrows can increase the amount of deadwood in both managed and old-growth forests. However, they are currently relatively rare events, and in managed forests their positive influence (from the biodiversity viewpoint) is often negated by removing the deadwood; consequently, they are of only minor importance for the majority of biodiversity at the European scale.

It should also be noted that factors contributing to biodiversity also coincide with those underpinning other aspects of sustainable forestry and associated ecosystem services. For instance, removing deadwood, branches, twigs, etc. also removes a source of soil humus and nutrients, while more frequent interventions (for wood extraction) also contribute to destruction of forest soil cover, increasing the risk of soil erosion—especially in hilly and mountainous parts of the EU. Gobin *et al.* (2011) provide several scenarios for residues removal from forests for bioenergy production and show that removal of 70% of wood residues and 25% of stumps leads to a serious decline in carbon fluxes and associated humus into the soil—especially pronounced in coniferous forests.

3.3 Protecting biodiversity

From the above discussion, it can be seen why old-growth forests are biodiversity hotspots, but also that managed forests play an important role. Biodiversity can thus be enhanced by (1) setting aside and protecting old-growth areas, (2) increasing deadwood and other structural elements in managed forests and (3) avoiding negative ecological impacts of management by including biodiversity in multi-functional forest management policies. The large differences in ecological and climatic conditions between eucalyptus plantations in Southwest Europe, poplar plantations in Eastern Europe, beech forests in Central Europe and boreal coniferous forests in the north require targeted measures, through both governmental and non-government processes, for protecting and increasing the biodiversity values in each region.

As already pointed out in section 2.1, diversity is important not just at the species level, but at the genetic level also. Genetic variations within species serve as a buffer against fluctuations of the environment (Larsen, 1995), and the many species in a biodiverse ecosystem provide genetic variation which contributes to the

adaptability and resilience of ecosystems (Fares *et al.*, 2015). This relationship can be shown as a hierarchy (Figure 3.1) where threats such as habitat loss and climate change show their impacts at the ecosystem level, while the response of species in the ecosystem will ultimately be determined by their genetic architecture. Legislation such as the Habitats Directive focuses on the protection of particular animal and plant species rather than genetic diversity. Moreover, it focuses on the protection of breeding sites and migration resting areas of individuals rather than on the maintenance of viable populations at larger spatial scales, hindering the development of cost-effective and scientifically-based comprehensive conservation strategies (Jokinen *et al.*, 2015).

An important aspect of the assessment and monitoring of biological diversity is the use of existing and emerging genetic analysis technologies. The integration of molecular approaches and techniques can give additional and/or novel insights into the genetic diversity and structure of target species for genetic conservation efforts. Existing efforts[12] need to be integrated into long-term strategies to identify the genetic diversity of target species, as well as providing a platform for the assessment and monitoring of conservation efforts. In addition, molecular analyses can provide indicators for assessing and monitoring biological diversity, for example by the assessment of soil microbial diversity, and the correlation with other ecological parameters, including ecosystem services such as nutrient cycling, carbon storage and turnover, water retention, soil structure regulation, resistance to pests and diseases, and regulation of above-ground diversity (Girlanda *et al.*, 2011). In addition, high-throughput DNA sequencing strategies can be used for analysis of complex environmental samples to assess functional and ecological biodiversity as well as for identification of rare and endangered species (Shokralla *et al.*, 2012). These approaches can give a quantitative measurement of the efficacy of various conservation measures,

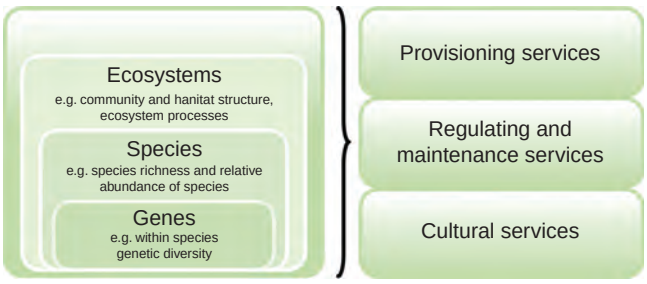


Figure 3.1 Levels of diversity- from genes to ecosystems, and their role as supporting other ecosystem services.

and assessment of different silvicultural approaches and management regimes. A long-term and stable policy commitment would allow such methods to be integrated into existing conservation and monitoring strategies.

International efforts to safeguard biodiversity and ecosystem services are pursued under the CBD, which adopted Aichi target 11; according to which the world's areas of particular importance for biodiversity and ecosystem services should be expanded by 2020 to at least 17% of the terrestrial world. Biodiversity is not evenly or randomly distributed at global, continental or local levels (Myers *et al.*, 2000; Hillebrand, 2004; Brooks *et al.*, 2006). Global and continental scale analyses of the priority areas for biodiversity are needed to inform country level implementation of land use decisions both for development and for biodiversity conservation (Pouzols *et al*., 2014; Di Minin *et al*., 2016). There is compelling evidence that exclusively national conservation planning will result in ineffective conservation outcomes and wasteful use of financial resources due to uncoordinated actions between countries. As an example, let us consider the Aichi Target above. The present global protection area network covers 19% of the ranges of nearly 25,000 species of terrestrial vertebrates. A globally planned and implemented expansion of the terrestrial protected area network to the 17% target would **triple** the number of protected ranges of terrestrial vertebrates to 61% (Pouzols *et al*., 2014). In contrast, exclusively nationally planned expansion of protected area networks would cover only 38% of the number of species ranges. To achieve the same level of species protection, a nationally designed network would have to protect 32% of the land surface—almost double that required for a globally designed network. The same principles apply to European biodiversity conservation, and a cost-effective pan-European protected area network should be based on a European-scale analysis of the priority areas for protection, which could then guide the implementation and expansion of protected areas in individual Member States.

Such a pan-European genetic conservation strategy was devised by the European Forest Genetic Resources Programme (EUFORGEN; De Vries *et al.*, 2012), taking into account the area of suitable habitat, the condition or the quality of the habitat and the spatial distribution of habitat patches (Hanski, 2005, 2011; Rybicki and Hanski, 2013). This would address the resilience and effectiveness of species protection by ensuring that spatial distributions of protected habitat patches are viable in the longer term. Such strategies

[12] For example, FORGER (www.fp7-forger.eu) and LIFEGENMON (http://www.lifegenmon.si/).

need to recognise that conservation of biodiversity is very much a land use question, and the protection of large continuous areas (*land sparing*) is challenging to establish in places that have already been converted to human use. For this reason, a combination of *land sparing and sharing* is a more realistic and potentially effective approach. Aggregating new conservation efforts in multi-use landscapes that would cover half of the landscape, within which about 30% of the area would be set aside (spared) and the remaining two-thirds shared, offers one possible effective approach (Hanski, 2011; Rybicki and Hanski, 2013; Kotiaho, 2017).

A review of the EU biodiversity policy in the context of climate change (van Teeffelen *et al.*, 2014) also identified several important policy gaps that this EASAC report confirms: (1) conservation targets should be designed such that they better match conservation needs; (2) targets need to be set in a spatially coherent manner across national scales; and (3) current monitoring tools for biodiversity conservation and ecosystem restoration seem to be insufficient to address these gaps.

3.4 Measuring progress in meeting biodiversity targets

Improving biodiversity also involves commitments to recovering degraded land under recent global conventions. For example, in 2010 the international community, including the EU, adopted a target to restore 15% of degraded ecosystems by 2020 (CBD Target 15), and in October 2015, the UN General Assembly set a new goal to reach a land degradation-neutral world by 2030[13].

Setting quantitative targets for the restoration or cessation of land degradation generates a need for a means of measuring progress. The key is not just to be able to measure the area degraded but also to establish the magnitude of degradation within each area (Kotiaho and Moilanen, 2015). This will be very different for an ecosystem that has been only slightly degraded compared with one that has been almost completely lost. There is thus a need for a common point of comparison: that is, a baseline that is based on scientific assessments, against which measurements can be compared to show how much degradation has been caused and how much restoration has been achieved.

With a globally agreed quantitative restoration target, a baseline is needed that ensures fairness and comparability when assessing the magnitude of degradation and the success of restoration among countries that are in different stages of economic development (UNEP, 2003). An ecosystems pre-degradation state, also known as its natural state, provides such a baseline (Kotiaho *et al.*, 2016). This state has no human-caused loss of biodiversity or of ecosystem functions. The natural state baseline is independent of societal values and the time of development, making it fair and comparable across different countries.

If a baseline were to be adopted from some recent past, developed countries that transformed their environment centuries ago from its original natural state will appear to have degraded their land less than developing countries that have degraded their environment more recently. With such a baseline, the 15% restoration target for developed countries unfairly becomes less demanding than for developing countries. This inequity is corrected when the natural state is used as a baseline for measuring the magnitude of degradation.

[13] http://www.unccd.int/en/programmes/RioConventions/RioPlus20/Pages/Land-DegradationNeutralWorld.aspx

4 Forestry in EU climate and energy policy

In considering the interaction between forestry and climate, there is a fundamental trade-off between using forests for carbon storage, and harvesting the wood. In some uses of wood (e.g. construction materials[14]), carbon continues to be stored for long periods, but in others (particularly biomass energy) the carbon contained in the wood is released to the atmosphere almost immediately. Harvesting immediately reduces the standing forest carbon stock compared with less (or no) harvesting (Bellassen and Luyssaert, 2014; Sievänen *et al*., 2014) and it may take from decades to centuries until regrowth restores carbon stocks to their former level—especially if old-growth forests are harvested.

When forest biomass is used to substitute for fossil fuels, it should also be noted that harvesting and processing of that biomass requires fuel inputs. Moreover, the combustion of forest biomass for power generation or heating will generally release more carbon dioxide to the atmosphere per unit of delivered electricity or heat than fossil fuels, owing to biomass having lower energy density and conversion efficiency (Ståhls *et al.*, 2011; JRC, 2013; Smyth *et al.*, 2016a; Soimakallio *et al.*, 2016). The overall climate effects of using wood for energy thus depend on the life cycle GHG emissions of the sources of the wood (short rotation coppice, harvesting residues or roundwood) and are highly case-specific.

Policies for the use of forest bioenergy need to take into account not only natural sciences but also social sciences because the physical aspects of wood production and the economic profitability of forestry must be integrated with other policy and economic objectives such as ensuring security of energy supplies, rural job creation, limiting carbon emissions, returns on investments as well as competitiveness in energy markets. Short-, medium- and long-term life-cycle analyses are needed to assess the costs, benefits and trade-offs of policy instruments and incentive structures for bioenergy. These must address the full range of climate impacts and other externalities in markets for forest biomass, which may take more than 100 years to grow and may then have lifetimes of a further 100 years or more. As already mentioned in section 1.2, applying the cascading principle and prioritising applications that store the carbon contained in the wood for long periods (e.g. construction) can delay the emission of its carbon content into the atmosphere. However, even when applying the cascade principle, because forest resources include low-grade biomass and other by-products (e.g. black liquor) that are suitable only for incineration, some carbon may be returned to the atmosphere in the short term. This chapter explores some of these issues and their implications.

4.1 Forest bioenergy and EU climate policy

4.1.1 On carbon neutrality

The use of biomass for energy is often linked to the concept of *carbon neutrality* (see review in Johnson, 2009). According to this concept, harvesting of forests and using wood for various purposes such as bioenergy may release carbon dioxide quickly after harvest, but these emissions are re-absorbed by the regrowth of the harvested stand over time, or by growth in other stands on a landscape scale which act as carbon sinks, thus compensating for the initial emissions[15]. On this simple model, forest biomass can be said to be carbon neutral because a mechanism exists for emitted carbon to be reabsorbed. The carbon neutrality argument has given a strong boost to policies that aim to increase the use of forests as a source of bioenergy and as a substitute for fossil energy, with forest biomass being classified as renewable, and currently contributing substantially to the EU's renewable energy targets (section 1.2.2).

The validity of the carbon neutrality concept has been intensively studied and has been shown to be highly simplistic. The inherent lower energy density of biomass means that more has to be burnt (relative to fossil fuels) to generate the same amount of electricity or heat; thus initial emissions are higher. Moreover, the length of time needed for those emissions to be compensated by the growth of new forests, called the carbon *payback time* (see below), can be substantial (Fargione *et al.*, 2008). Unsustainable utilisation of forests (for example leading to land use change, or conversion of old-growth forests to intensively managed, shorter rotation forests) unavoidably decreases carbon storage in living trees and forest soils. With SFM, the net effect of harvesting on GHG emissions depends critically on how the harvested timber is utilised. Using wood in durable commodities and construction stores carbon over long periods, while energy production causes immediate carbon release.

The concept of carbon neutrality must therefore be considered on a case-by-case basis together with the

[14] Materials such as steel and concrete have high GHG footprints which can be avoided by substitution (Schlamadinger *et al*., 1996; Pingoud *et al*., 2010; Sathre and O'Connor, 2010).

[15] This concept starts with the harvest and has led to the term 'carbon debt' to describe the carbon that needs to be 'repaid' through future growth. But an alternative model would see the carbon released as using a carbon credit from the past that is cashed in through its use (Pelkonen *et al*., 2014). Discussion must thus make it clear the reference time being used.

related payback period. Long payback periods mean that use of forest bioenergy may jeopardise short- (less than 10 years) and medium-term (10–50 years) emission reduction objectives even if longer-term 'carbon neutrality' can be achieved (Bellassen and Luyssaert, 2014; Sievänen *et al.*, 2014). Fundamental to the net carbon balance effects of forest-based biomass energy is the *type of forest biomass* utilised. Where the biomass would decompose fast if not utilised (for example, in the case of some harvest residues), there could be an overall beneficial climate effect if that biomass were used to produce energy in place of fossil fuels (although with a negative effect on biodiversity; Toivanen *et al.*, 2012). In countries with long traditions of forest industry, much of the wood-based energy is currently produced from residual or waste materials from the forest industry (for example black liquor) with such beneficial climate effects.

However, if trees with a large ongoing carbon storage potential are harvested, then the emissions from burning the biomass would be associated with the loss of a carbon sink, and the net effect on the climate is likely to be negative (Smyth *et al.*, 2016b; Soimakallio *et al.*, 2016). Further, harvesting reduces forest soil carbon levels (Nave *et al.*, 2010; Achat *et al.*, 2015), and studies in which these losses are accounted for have shown that the use of forest biomass for energy production may yield up to 40% higher carbon dioxide emissions than fossil fuel (Mäkipää *et al.*, 2015; Bradford *et al.*, 2016; see Matthews *et al.* (2014) for a review). The recent expansion of the use of biomass in many countries has extended the range of biomass feedstocks to include roundwood, from which the climate impacts depend very much on the growth rate of the tree species in question. Slow-growing trees have long payback times and JRC (2013) notes that '*in the case of stemwood harvested for bioenergy purposes only, if all the carbon pools and their development with time are considered in both the bioenergy and the reference fossil scenario, there is an actual increase in CO_2 emissions compared to fossil fuels in the short-term (few decades)*'.

In short, utilising forests for bioenergy combines many factors that vary over time and from case to case, so it is too variable to be labelled simply as carbon neutral (Schulze *et al.*, 2012). The label of carbon neutrality obscures the reality that carbon management does not offer any general context-independent justification to increase forest utilisation. Additionally, it hides the significant possibilities to promote the use of forest ecosystems as carbon sinks, which should be considered an essential component of climate change mitigation through forest management.

4.1.2 Comparing forest biomass energy with other energy sources; life cycle assessment

Under the EU's non-binding recommendations for Member State rules on sustainability of solid biomass[16], biomass should deliver a minimum level of GHG 'savings' over their life cycle (cultivation, processing, transport, etc.) compared with fossil fuels, and such standards are already applied or exceeded in some Member States. This may give the impression that switching from fossil fuels to biomass reduces emissions; however, this would be misleading and an objective comparison of emissions is complex and the source of considerable controversy[17]. We attempt to summarise some of the key factors in this section.

The current method for measuring GHG 'savings' is to compare the emissions from burning fossil fuels with the emissions from cultivating, processing and transporting a quantity of biomass with similar energy-producing content. This calculation does not include the release of (biogenic) carbon contained in the biomass on combustion (see next section), nor the secondary effects on the carbon stocks of the forest that has been harvested for biomass. In addition, the inherently lower energy density and lower combustion efficiency of biomass lead to carbon dioxide emissions per unit of energy produced being 1.2, 1.5 or 2 times higher than when using coal, diesel oil or natural gas, respectively (IPCC, 2006). This means that, as already noted, switching from fossil fuels to forest biomass to produce the same amount of energy, inevitably increases carbon dioxide emissions.

In the previous section, we introduced the carbon payback concept to refer to the time needed to reabsorb the amount of carbon dioxide released by the combustion of the harvested biomass. However, in reality, the biomass harvested for bioenergy purposes would have continued to grow and absorb carbon dioxide for at least some time. Moreover, other scenarios are possible—for instance, a previous semi-natural forest could be converted post-harvest to plantation forest, or agriculture. The net climate effects of harvesting a forested area for bioenergy will thus be a combination of the emissions from burning and the loss of carbon absorption potential after harvest. This means that even after the carbon payback period has passed, there may still be a lower carbon stock than if the biomass had not been harvested, and additional

[16] The recommendations in COM (2010)1 apply to energy installations of at least 1 megawatt thermal heat or electrical power, and forbid the use of biomass from land converted from forest, and other high carbon stock areas, as well as highly biodiverse areas. They require that biofuels emit at least 35% less GHG over their lifecycle (cultivation, processing, transport, etc.) compared with fossil fuels. For new installations, this amount rises to 50% in 2017 and 60% in 2018.

[17] As illustrated by the conflict as we went to press between Chatham House and IEA Bioenergy (https://www.chathamhouse.org/sites/files/chathamhouse/publications/research/2017-02-23-woody-biomass-global-climate-brack-final2.pdf) and IEABioenergy (http://www.ieabioenergy.com/publications/iea-bioenergy-response/).

time will be needed to reabsorb sufficient carbon to compensate for this loss and achieve 'carbon parity'. As can be seen in Figure 4.1, until the parity payback time is reached, atmospheric concentrations of carbon dioxide will be higher than if biomass had not been used to replace fossil fuels. Parity payback periods vary greatly, with cases where slow-growing trees would be harvested from boreal forest to replace fossil fuels extending to 100–300 years (see, for example, McKechnie *et al.*, 2011). These inherent uncertainties in the use of forest biomass have long been recognised (see, for example, EEA, 2011).

Three scenarios based on using different types of forest biomass are presented below to illustrate the potential policy implications of different payback periods[18].

Scenario 1. This reflects the historical practice in much of EU forest management, where bioenergy is part of the forest products chain and comes from residues, by-products of processes such as pulping (black liquor), and low-quality wood, sawing losses, post-consumer waste and such. In Scandinavia, for instance, whole villages are heated with residual heat from pulp mills or bioenergy units producing both electricity and heat from such residues. Available evidence indicates that these sources have parity payback periods of decades at most.

Scenario 2. The scenario of increasing extraction of forest biomass for bioenergy was recently analysed by Nabuurs *et al.* (2017). Eight forest types across Europe with contrasting growth and management characteristics were considered, and the time required to reach carbon parity calculated when increasing harvesting rates, rates of thinning or residue removal—while maintaining existing environmental and biodiversity rules (Nabuurs, 2006; Elbersen *et al.*, 2012; Verkerk *et al.*, 2014). They compared biomass with both coal and natural gas fossil fuel comparators, and found that the time to reach parity ranged from short (approximately10 years with increased use of forest residues), through decades to 100 years (increased rate of thinning), to about 100 to more than 500 years when felling was increased for the purpose of bioenergy and certain types of forest were involved (Figure 4.2).

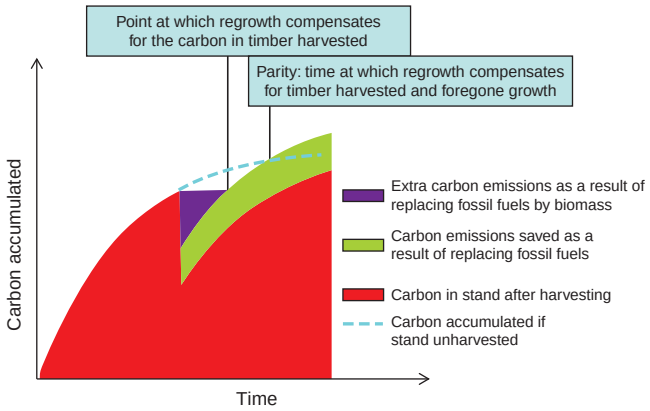


Figure 4.1 Conceptual diagram of carbon debt and parity. Source: adapted from Nabuurs et al. (2017).

Scenario 3. This is applicable in countries that use forestry biomass for electricity generation and/or heat generation in large-scale power plants. Mitchell *et al.* (2012) compared net GHG emissions under scenarios where natural forests and plantation forests were left to grow, relative to being clear-cut every few decades to provide fuel for power plants. They found carbon payback periods that ranged from 'centuries' (older natural forests) to 'decades to centuries' (plantation forests). Stephenson and Mackay (2014) considered a range of scenarios from using forestry by-products to felling whole trees to provide biomass for electricity generation. Some of their findings are summarised in Table 4.1, and show that pellets derived from sawmill residues or forest residues that would otherwise be burnt offer significant GHG savings over a 40-year period. However, where coarse residues (for example trunks and roots) or whole trees are taken, GHG savings only occur over 40–100 years (or longer).

The implications from a climate perspective of such huge ranges in potential impacts are thus substantial. While using sources of residual wood (for example residues, tree thinning) for energy can make a positive contribution to climate mitigation within a decade or so, expanding demand to include whole trees can swiftly move to scenarios that exacerbate climate change for centuries. In this context, a recent analysis by the European Forest Institute (Berndes *et al.*, 2016) recognises that the economic and environmental benefits of the use of forest biomass for energy are highly variable and require appropriate measures to promote best practices in forest management for climate change mitigation. The compatibility of these scientific conclusions with the current regulatory framework is considered below.

An emerging question is whether basing comparisons of wood-based bioenergy with emissions from fossil fuels is becoming outdated, because other renewable energy technologies (including solar and wind) that have very low GHG emissions are fast becoming cost-competitive and increasing their penetration into EU energy markets. It may thus be more appropriate from

[18] It has been argued that carbon balances should not be assessed at the stand level since at landscape level depletion of carbon in one stand may be compensated by growth in a stand elsewhere. For scientific analysis of the impact on climate forcing, however, it is necessary to compare the effects of various bioenergy harvest options against a baseline of no bioenergy harvest (or other credible counterfactual scenarios) for the same area of forest. Such studies provide information on the impacts of changes at the stand level, which can then be integrated with other factors (economic, regulatory and social) that may influence effects at landscape level.

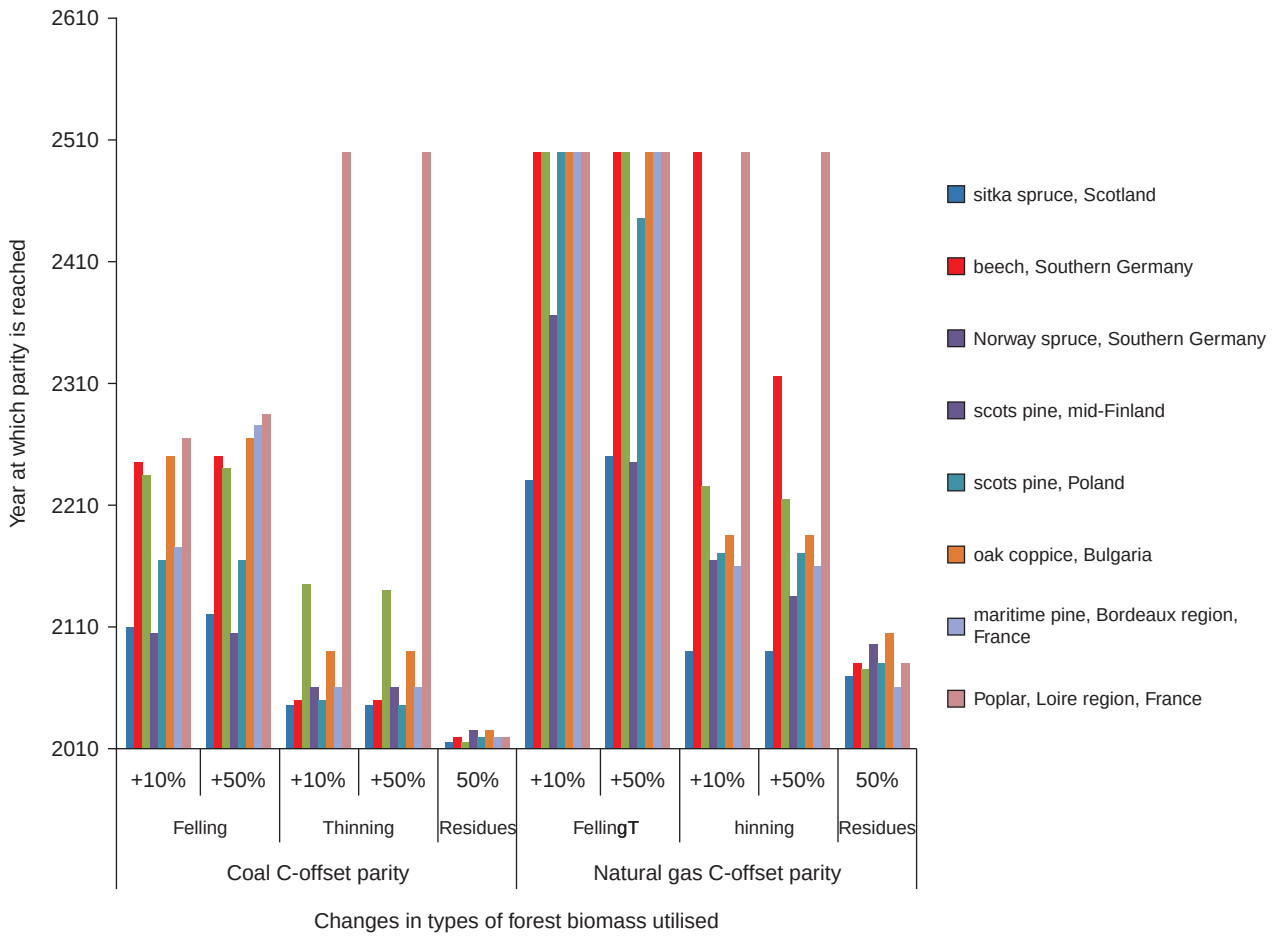


Figure 4.2 Year of parity repayment for different rates of harvesting, thinning and residue removal against coal, gas for eight forest types in Europe (Nabuurs et al., 2017).

Table 4.1 GHG impacts of bioenergy scenarios (40 year); adapted from Stephenson and Mackay (2014)

	Greenhouse gas impacts in $kgCO_2$/MWh electricity (natural gas and coal reference values are 440 and 1000 $kgCO_2$/MWh respectively)		
	<100	100–400	>400
Woody residues	Forest residues and sawmill residues that would otherwise be burnt as waste. Trees killed from natural disturbances that would otherwise be burnt as waste.	Fine residues that would otherwise be left to decay. Coarse residues that would otherwise be left to decay (for a southern US forest).	Coarse residues that would otherwise be left to decay in the boreal forest. Trees killed from natural disturbances that would otherwise be left in a boreal forest.
Roundwood and energy crops	Increasing the yield of a plantation without increasing the rate of harvest. Wood from the forest that would otherwise be converted to agricultural land. Converting land that would otherwise revert to grassland into biomass plantations.		Additional wood output from increasing the harvest rate of forests. Wood from forests that would otherwise be harvested less frequently Converting forests into energy crop plantations. Converting land that would otherwise revert to forest into biomass plantations.

a climate perspective to compare the climate impacts of bioenergy with those of other renewable energy technologies rather than with those of fossil fuels.

4.1.3 Forestry in the EU: GHG emission accounting principles and climate and energy policy

In the current EU climate policy framework, forests and forest bioenergy are included in the LULUCF sector that is not yet part of the EU's emission reduction target for 2013–2020. According to these accounting principles, Member States must report on changes in forest land areas, and any related decreases in carbon storage due to deforestation must be compensated by emission reductions elsewhere. Changes of carbon stocks in existing managed forests are compared with forest *reference levels* (anticipated carbon sink or the carbon sink at some base year).

Forest carbon sink or stock changes are measured by applying the 'instantaneous oxidation' principle, which assumes that carbon in harvested trees is instantaneously released to the atmosphere when harvested. Under this accounting principle, forest biomass used for bioenergy is assumed to have already released its carbon to the atmosphere and this is why, to avoid double accounting, its emissions are not accounted for when the wood is actually burnt. Because some fraction of carbon in harvested trees is in reality stored longer in wood-based products, Member States are required to observe changes in the pool of wood-based forest products as well.

In the accounting principles proposed in July 2016[19], carbon removals from the atmosphere above the forest reference level can be used partly to compensate for excessive emissions in other sectors. A critical feature in these latest proposals is thus how future forest reference levels for Member States will be specified. If the reference levels and sinks are lower (in absolute terms) than actual 'business as usual' levels, countries have the possibility to increase emissions from managed forests by increasing bioenergy production and decreasing carbon storage. To avoid creating an incentive towards such a perverse outcome, it is important that future reference levels should be set on an objective basis.

One effect of the 2009 RED and its resulting incentives has been that in some Member States substantial amounts of forest biomass have been imported (especially from USA and Canada) to produce electricity—either in dedicated biomass boilers or in co-firing with coal. This has allowed the importing country to report a reduced level of carbon dioxide emissions because emissions from biomass are not counted at the point of combustion. However, in reality such reported reductions do not equate with a contribution to climate change mitigation; rather, the importing country is taking advantage of the accounting rules and exporting responsibility for reporting emissions to the country that provided the feedstock and is thus responsible for LULUCF reporting.

The uncertainties and inconsistencies in assessing and regulating the use of solid biomass for energy have attracted much attention and led to the current EU non-binding sustainability criteria, while the European Commission has also reported on the use of biomass in Member States (EC, 2014). More recently (during 2016), the Commission has been consulting on post-2020 biomass sustainability criteria and has revised the criteria in its proposals for a new RED (EC, 2016a). The latter has taken into account an impact assessment that summarises the basic scientific issues and is in close agreement with the findings of this report, as shown in Box 6.

4.1.4 Alternatives to existing GHG emission accounting principles

According to general economic principles, emissions of harmful substances such as carbon dioxide are seen as 'negative externalities' (Stern, 2006), which are not taken into account by private actors in market economies, and thus require market interventions such as legal restrictions, taxation or emissions trading. In contrast, carbon storage in forests represents a 'positive externality' (a beneficial factor not recognised by the market and thus not priced), which should be promoted if it is to be taken into consideration by private actors in their decisions. As described above, current incentives feature prominently in using forest biomass for renewable energy, but forest-based carbon sequestration's potential contribution to negative emissions remains an opportunity yet to be realised (Ellison *et al.*, 2014).

The adjustment of economic incentives/disincentives to discourage emissions and encourage carbon sequestration can be characterised in the '*cleaner earns, polluter pays principle*'. This simple principle would suggest that carbon storage (i.e. negative emissions) should be subsidised and emissions from forest bioenergy should be accounted for and controlled

[19] In July 2016, the European Commission launched a proposal for a regulation on the inclusion of GHG emissions and removals from LULUCF within the 2030 Climate and Energy Framework that aims at a total emission reduction of minus 40% by 2030 (COM 2016 479 final) in all sectors. In this new LULUCF proposal, removals from managed forest, minus a reference level, can be cumulated over the 10-year commitment period. The main target set is the 'no debit rule': that is, concerning LULUCF, a Member State has to perform as well as in the past and emissions from within this sector (from cropland, grassland, etc.) can be compensated for by sinks in the same LULUCF sector limited in total to 280 million tonnes. Further, there is very limited flexibility towards the Effort Sharing Regulation (ESR), which allows compensation of emissions in ESR sectors – transport, housing, waste and non-CO_2 agriculture – limited to a maximum annual 3.5% of Member State base year emissions (approximately 196 Mt CO_2/yr).

Box 6 Scientific issues relevant to the use of forest biomass for energy in the European Commission's 'Clean Energy for all Europeans' package

The Commission has previously (EC, 2014) noted that biomass is key to achieving the 2020 renewable energy targets and the EU long-term decarbonisation goals by 2050. The Commission also noted that, for the post-2020 period, an improved biomass policy would need to be developed '*in order to maximise the climate and resource efficiency benefits of biomass in the wider bioeconomy, while delivering robust and verifiable GHG emission savings and minimising the risks of unintended environmental impacts'*. More recently, the Commission published a package of proposals entitled 'Clean Energy for all Europeans' (EC, 2016a), which includes proposed revisions to the RED and the role of bioenergy. In its analysis, the Commission provides a summary of its assessment of solid biomass issues with which EASAC strongly concurs—specifically with the following (EC, 2016b):

- The Commission's recognition of the basic problems. Here, the first two problems are particularly relevant to this report (*1. The climate performance of bioenergy varies, and in particular biogenic CO_2 emissions associated with an increased demand for forest-based biomass may lead to minimal or even negative greenhouse gas savings compared with fossil fuels. 2. The production and use of biomass for energy can lead to adverse environmental impacts on biodiversity, soil and air quality.*)
- The Commission's recognition that '*The impacts on climate change of solid and gaseous biomass used for heat and electricity are complex and can vary significantly (from very positive to very negative impacts, i.e. reducing or increasing emissions compared to fossil fuels). However, a growing body of scientific evidence is available to understand these impacts.*'
- Confirmation that the primary objective of bioenergy is climate change mitigation.
- Full recognition of the importance of the timescale given the lengthy re-growing period for forest biomass.
- Recognition of the importance of biogenic emissions from pre-existing carbon pools.
- Recognition that as demand for bioenergy increases, there will be a shift from low-impact sources with a positive contribution to climate change mitigation (forestry by-products and residues, black liquor, low-quality roundwood, etc.), through sources with a more marginal contribution (for example small roundwood which competes with other uses, removing the carbon stock in stumps and other coarse residues), through to sources with a potentially exacerbating effect on climate change (for example felling whole trees for production of wood pellets).
- The Commission's recognition of the inherent weaknesses of the split in accounting, and comments that the zero rating for bioenergy emissions at the point of combustion has often been misinterpreted as meaning that biomass combustion is always carbon neutral.

through appropriate means, such as taxation, emission trading or legal restrictions (Tahvonen, 1995). Policies aiming to motivate owners to increase the carbon storage in their forests exist. For instance, in New Zealand, forest owners are compensated according to carbon stored, and in Ontario (Canada), forest owners with higher than a benchmark carbon sequestration can earn carbon credits to be sold in emission trading (Asante and Armstrong, 2016). Models thus exist for payments for such ecosystem services. It is, however, unclear whether the present accounting framework (with its IPCC origin) can provide the basis for an economically efficient scheme for controlling these externalities by means of incentives.

4.2 Bioenergy production with fast-growing coppices

One option for producing forest bioenergy is to use short rotation coppicing (SRC) as the source of biomass fuel. Decades-long research has led to solid SRC expertise in several countries, with practical experience of growing poplar and willow at high densities, and this has been translated into best practice guidelines[20]. Yet, the environmental impacts and economic viability of SRC as an alternative energy source to fossil fuels are still under debate, and a widely accepted methodological approach for performing the required life cycle assessment is lacking. For example, the net GHG budget of different management approaches depends on the amount of energy used (for instance in irrigation, pesticides), and on the emissions of non-carbon-dioxide GHG such as methane and nitrous oxide, which are influenced by land-use changes and fertiliser use. These last two gases have global warming potentials that are substantially greater than those of carbon dioxide[21].

Despite such uncertainties, recent reviews suggest that carbon emissions per unit of energy produced by SRC (electricity or heat) are substantially below those associated with fossil fuels (Njakou Djomo *et al.*, 2013, 2015). The rapid rotation also makes the carbon payback time relatively short.

There are also suggestions that SRC could be a multi-purpose, multi-functional source of woody crop production. SRC has in practice sometimes been accompanied by the establishment of other coppice plantations for energy purposes that, through an increase in forest areas and improved forest management, can also increase forest carbon stocks (Miner *et al.*, 2014). However, studies have shown that bioenergy from SRC is not yet economically viable across all European countries (El Kasmioui and Ceulemans, 2013).[22]

[20] For example, http://www.seai.ie/Renewables/Bioenergy/Willow_Best_Practice_Guide_2010.pdf; http://www.forestry.gov.uk/fr/infd-8a5kl3

[21] The global warming potential of methane ranges from 34 to over 100 depending on the time frame; while that of nitrous oxide is 268–298 (IPCC, 2013).

[22] An approach to mitigation of climate warming via negative emission technologies using bio-energy with carbon capture and storage (BECCS) has been proposed. However, all negative emission technologies lack proper evaluation of economic feasibility and true climate impacts (e.g. the land use intensity and water requirements of BECCS are quite high) (Smith *et al.*, 2015).

4.3 Conflicts in land use for bioenergy production

The above analyses show that there are potential trade-offs and conflicts between forest harvesting policies, climate change mitigation and biodiversity. Some of the key potential conflicts include old-growth versus shorter rotation periods; residual biomass clearance versus dead and decaying wood as a source of biodiversity and soil fertility; and land use conflicts (reviewed in Felton *et al.*, 2016). Such inherent conflicts mean that conventions and treaties in different sectors may contradict each other. For example, in 2009 the EU's RED set a binding target of 20% of final energy consumption from renewable sources by 2020, and this has since been raised to 27% by 2030. Simultaneously, the CBD stated that by 2020, the terrestrial protected area networks should be increased to 17% and that 15% of degraded lands should be restored (Chapter 3). It is necessary to consider how far these separate objectives are compatible with each other.

To produce biomass for energy requires more land than most other energy sources (Brook and Bradshaw, 2014), and therefore raises a potential conflict by limiting the land area that is available for biodiversity conservation (Wise *et al.*, 2009; Foley *et al.*, 2011). For instance, the favourable GHG reductions offered by SRC (or equivalent energy crops including *Miscanthus*) relative to forest bioenergy sources may lead to an increased demand for land, which in turn may also compete with areas valuable for biodiversity. Indeed, Santangeli *et al.* (2015) combined data on the global distribution of the most biodiverse areas with global data on land-based renewable energy production potential (including bioenergy from dedicated plantations for *Miscanthus*) and found a considerable overlap between areas with bioenergy production potential and top biodiversity areas (approximately 40% of the bioenergy production potential in Europe is situated in the top 30% of the most biodiverse areas).

As a result, Kareksela *et al.* (2013) argue that, when assigning priority for land use, the potential for renewable energy production should be assessed in comparison with the needs of biodiversity protection or land restoration. In this context, biodiversity in SRC is higher than in agriculture[23] but less than in some areas (such as grasslands) that it could replace. Informed by an EU-wide analysis of such trade-offs, Member States would be able to target renewable energy production locally in areas that would least harm biodiversity. The commonly cited option of growing SRC on degraded (sometimes called marginal) land may not be an economically viable solution owing to the increased costs and lower yields.

[23] For example, the reduced disturbance in SRC allows for perennial plant species, potentially providing a stable refuge and food sources for various invertebrates (see Rowe *et al*., 2011), for breeding birds of shrubs and hedges (see Londo *et al*., 2005) and for gamebirds (see Baxter *et al*., 1996). Creating habitat heterogeneity by maintaining a diversity of plantation ages and biomass crops also enhances the diversity of small mammal species across landscapes (Moser *et al*., 2002).

5 Opportunities for optimising forest management towards multiple objectives: wood production, climate change and biodiversity

Society's expectations of the benefits to be received from forests have expanded in recent years from the historical provisioning services (timber, pulp, etc.) to others which include contributing to climate change mitigation and biodiversity protection. A key challenge is to ensure that current scientific evidence on forests' multi-functional role can be applied in forest policy and silvicultural management, and better account for the potential trade-offs between various social, economic and ecological contributions. Developing improved forest management alternatives requires sharing new knowledge between forest experts, the forest industry and various interest groups. Here we consider some of the conclusions of our assessment of the current science with direct implications for management in different parts of Europe, and include examples of national policies for each of the main forest types.

5.1 Boreal forests

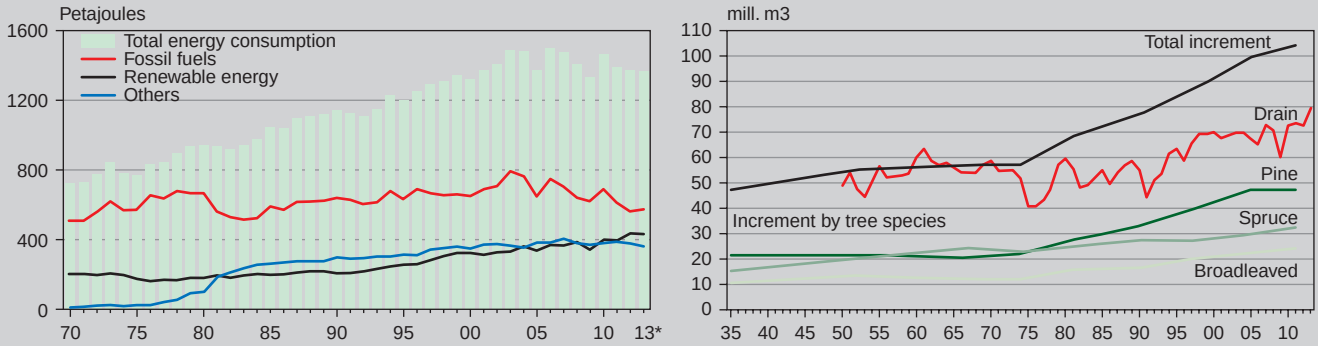
Currently, Northern European (Fennoscandia and Baltic countries) forests are widely managed for wood production using intensive silvicultural management practices such as clear-cuts followed by planting or other artificial regeneration methods (Kuuluvainen, 2009). Earlier and to some extent even nowadays, the primary objective was to reach maximum sustainable yield for timber production. This objective is, however, too narrow even from the point of view of timber production and should be extended to include prices, costs, interest rate and forest owners' financial and other objectives (Samuelson, 1976). Taking these broader objectives into account may lead to changes in the choice of tree species, planting density and timing of harvesting activities in sustainable and economically viable forestry (see, for example, Kuuluvainen *et al.*, 2012; Tahvonen *et al.*, 2013). Such observations have recently led (for example in Finland) to diversified forest management recommendations that differ from the traditional volume maximisation of timber production, and that receive strong support from both the public (Li *et al.*, 2004) and forest owners with varying objectives. Moreover, such diversification helps to balance the multiple objectives in forestry, such as recreation, biodiversity conservation and climate change mitigation.

From the carbon management perspective, the management of Northern European forests may need to change to properly integrate both wood production and carbon sequestration. Given an adequate economic price for carbon emissions, including this in the economics of forest management would imply major change. It would become economically rational to increase planting density, to postpone intermediate harvests (thinning) and to apply longer rotation periods, relative to forestry focused on previous timber production objectives (Van Kooten *et al.*, 1995; Pihlainen *et al.*, 2014). In the case of a price for carbon of approximately $50 per tonne of carbon dioxide, it would become economic to increase the carbon stored in forests by up to 40% and, in the long run, the market supply of wood would increase as a consequence of increased forest stocks. Importantly, the costs of optimising storage of carbon through changes in forest management would be considerably lower than alternative climate change mitigation methods, thus offering a lower potential cost to achieving climate targets (Pihlainen *et al.*, 2014). Further, those management choices that lead to increases in albedo and to forest coverage that produces more climate-cooling aerosols can be considered generally climate-friendly. This wide range of management options presents a challenge for the LULUCF policy to provide appropriate incentives for changes in forest management. Two examples of approaches to the multiple objectives of boreal forestry are given in Box 7.

Although forest biodiversity does not have an explicit economic price, recognition of the trade-offs could also include biodiversity protection through forest management in Northern regions. Forest biodiversity is dependent on decaying wood that is almost absent in boreal artificially regenerated forests. To increase its quantity, one measure is to shift from single-species forests towards more heterogeneous, mixed-species forests where some trees are left to decay without harvesting. Other positive outcomes from mixed-species forests include higher aesthetic and recreational values, as well as reduced stand vulnerability to forest fire, pest and pathogen damage. Additionally, the risks, uncertainties and increasingly observed damage caused by climate change may favour an increase in heterogeneous mixed-species forests, as they provide forest managers with wider options for coping with future situations (Gauthier *et al.*, 2015). For instance, thinning and selection cutting aimed at increasing species diversity may be used to support more drought-resistant species and reduce the risk of fire and insect infestations. Transforming some fraction of single-species stands into mixed stands, would offer a promising risk-averse strategy and lead to greater vitality and resistance against abiotic and biotic disturbances. Such approaches are supported by recent research

Box 7 Boreal forest policies (multi-functionality)

The economic role of forestry is large in **Finland** (the forest industry is responsible for about 20% of exports). In spite of intensive forest utilisation, forest resources in Finland have been continuously increasing over the past half a century. The use of wood-based energy has been increasing and accounted for approximately 35% of total energy consumption in 2013 and using around half of the annual wood consumption (mainly from forest industry by-products). Bioenergy is the main component of Finland's renewable energy which constitutes 32% of total energy consumption (see left panel on figure below).



Left: Total energy consumption by form of energy, 1970–2013. Right: annual increment of growing stock and drain 1935–2013. (Sources: Statistics Finland, Finnish Forest Research Institute/LUKE.)

In November 2016, the Finnish Government announced its ambitious new climate and energy plan for 2030, which aims to increase the role of forests in both energy production and climate change mitigation. It includes the goal of abandoning the use of coal for energy by 2030, and achieving a carbon-neutral energy system by 2050. The use of forest biomass for advanced transport fuels will be increased through biorefining (bioliquids and biogas); financial incentives (subsidies) will encourage using forest chips and forest industry by-products for combined heat and power, and for heating. An operating subsidy scheme for electricity produced from wood chips will continue at least until 2018.

The plan has major consequences for Finnish forest carbon storage and biodiversity values. It implies an intensification of historical forest use (see right panel on figure above) by increasing harvests from the current 60 million m^3 to approximately 80 million m^3 annually, to reach more than 50% of renewable energy by the 2020s. This will significantly reduce the forest carbon sink in the near future to 13.5–20 from the current 22–50 million tonnes carbon dioxide per year (http://tietokayttoon.fi/en/article/-/asset_publisher/10616/selvitys-hallitusohjelman-energia-ja-ilmastotavoitteet-saavutettavissa). The decline of carbon sinks resulting from increased biomass use is suggested to be offset by fortifying the growth and carbon-binding capacity of forests in the long run, by mapping out the afforestation of treeless areas and reducing the clear-cutting of forests in connection with infrastructure and transport construction. However, the viability of these measures has been questioned by forest experts (http://www.bios.fi/publicstatement/publicstatement240317.pdf). The impacts of increased harvests to forest biodiversity are foreseen to be large, and will critically depend on effective biodiversity conservation measures. Finland has a system that allows payment for ecosystem services for protecting biodiversity and other non-use values of forests, albeit the budget for this purpose is small.

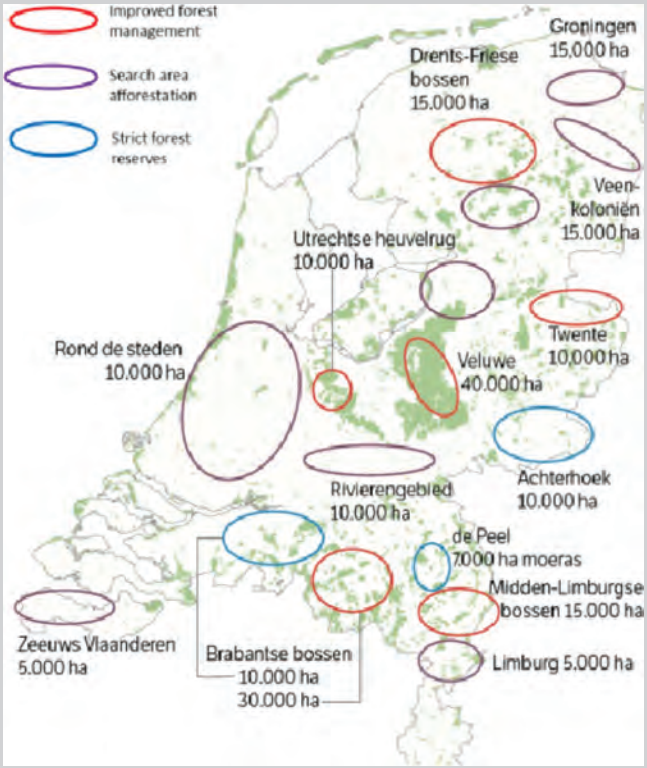
Also in the boreal biogeographical zone, **Estonia**'s forestry development plan was adopted in 2011, in which the productivity and vitality of forests and their multiple and efficient use was cited as the main goal. The plan has specific targets including protection of habitats and natural environment, diversifying recreation options, and supporting through R&D and other measures the competitiveness and adaptability of forest sector enterprises. The intensity of Estonian forest management ranks between Scandinavia and Central Europe—with a moderate intensity based on strong silvicultural practice. Annual removals have increased recently to 90% of the annual net increment, and therefore raise concerns about maintaining biodiversity and habitats. To balance economic and technological functions, 10.4% of forest area is strictly protected and restrictions are applied to an additional 14.7%. Debate continues on other measures including increasing the harvesting age in commercial forests and strengthening strictly protected areas.

which shows a positive correlation between biodiversity and forest productivity (Liang *et al.*, 2016).

However, many of the boreal forests have been subject to intensive silviculture for centuries, and this has led to a homogeneous forest structure with even-aged and single-species forests dominating. This structure may be expected to continue and even to become more widely adopted as a consequence of policies aiming to increase harvesting for pulp, timber and bioenergy, but contrasts with the need to manage forests with the aim of increasing their adaptation capacity (Gauthier *et al.*, 2015). Management strategies such as continuous-cover silviculture, integrated with increasing tree species diversity and landscape heterogeneity, offer alternatives that simultaneously contribute to the maintenance of forest cover, the conservation of carbon stocks, and the support of biodiversity and social and cultural values. Additionally, new research calls into question whether the economic viability of boreal forests is dependent on clear-cutting (Tahvonen and Rämö, 2016). Continuous cover forestry – when skilfully combined with existing forest management options – can contribute to stand and landscape heterogeneity and simultaneously provide ecologically and socially beneficial outcomes.

Box 8 Temperate forest policies (multi-functionality)

On 24 October 2016, organisations connected to forests and wood in **the Netherlands** released a 'National Action Plan Forest and Wood', which was endorsed and signed by the Prime Minister at a National Climate Summit. Organisations representing forest owners, non-governmental organisations and industry proposed measures that will lead to reduced carbon dioxide emissions from the Netherlands, sequester carbon dioxide and provide more renewable woody materials. The plan envisions afforestation of 100,000 hectares, better forest management in 200,000 hectares, establishment of reserves on 20,000 hectares and increased building with wood in the housing sector. The plan will lead to an additional 4 million tonnes of carbon sequestration and an additional supply of 0.8 million m^3 of quality wood to the industry. The locations of the various actions are shown in the figure below.



Envisioned diversity of actions as proposed in the Netherlands Action Plan (Nabuurs et al., 2016.)

In one example of the continental area of the temperate zones, the **Austrian** Forest Strategy 2020 aims to guarantee the sustainable management and maintenance of Austria's forests, through debate and consensus generation among all stakeholders. The overall objective is to ensure and optimise the ecological, economic and social dimensions of SFM in a well-balanced manner. It aims to increase the value and potential of the Austrian forestry and timber industry and ensure that forests can continue to effectively perform their natural 'functions', such as regulating the microclimate and acting as a carbon sink, for present and future generations.

To this end, policies and targets are being developed in the following seven areas: (1) contributions to climate protection; (2) health and vitality; (3) productivity and economic aspects; (4) biodiversity; (5) protective functions; (6) social and economic aspects; (7) Austria's international responsibility for SFM.

5.2 Temperate forests

In the Atlantic area of the temperate region, one example of a national plan involving multi-functional objectives can be seen in the Netherlands (Box 8).

Forests in the continental region of Central Europe (see an example from Austria in Box 8) have suffered frequent wind damage in recent years, and mature trees in an even-aged forest with homogenous structure tend to be more exposed to windthrow than uneven-aged, mixed, heterogeneous forests. Transforming single-species forests into mixed forests and converting them into highly structured uneven-aged forests that are then managed in a continuous-cover (close-to-nature) forestry system, may thus increase the resilience of Central European forests against natural disturbances and climate change impacts (Brang *et al.*, 2014). Silvicultural measures such as reductions in rotation times (traditionally long in parts of Europe) may decrease the vulnerability towards storm and insect damages, as old and large trees are often more vulnerable (Meilby *et al.*, 2001; Schmidt *et al.*, 2010). This is because shorter rotation times would lead to lower tree heights and reduce storm damage risks on exposed sites, while younger trees are less prone to insect attacks and diebacks from climatic extremes. Such

Box 9 Mediterranean forest policies (multi-functionality)

Portugal has a high percentage of forested area, having increased from 7% in the 1870s to 35% in 2015. The predominant species are *Pinus pinaster*, *Eucalyptus globulus*, introduced in 1852, and two oak species, *Quercus suber* and *Quercus rotundifolia*, that form the highly productive and biodiversity-rich 'montado' ecosystem. Forest fires have been a recurring problem since the 1970s, accounting for an average annual burnt area of 106,000 hectares from 1980 to 2015. This trend has implied an average annual loss of total forest area of about 10,000 hectares per year in the past 15 years.

Recently, the Portuguese Government released a legislative package for improved forest management and planning, reforestation, afforestation, forest fire prevention and fighting, which is under public discussion. The new legislation addresses the challenges of forest adaptation to climate change and ways to improve the forest contribution to carbon sequestration. The LULUCF sector in Portugal contributed an average annual sequestration of 10.8 million tonnes CO_2e in the period 2011–2015 (UNFCCC, 2016). Recent research has shown that the Mediterranean forest is already being affected by climate change (IPCC, 2014) and that the montado in the southern part of the Iberian Peninsula is particularly vulnerable to high-end climate scenarios that go above the Paris Agreement 2 °C increase in temperature (Guiot and Cramer, 2016).

a policy would, however, have trade-offs with carbon storage and biodiversity (which would be improved by longer rotation periods (Yousefpour and Hanewinkel, 2009)). Some traditional forest management methods such as coppicing and wood meadows or non-intensive forms of tree and group selection forest management, used in Central European countries to different degrees, can also promote high species and structural diversity. Selection cutting maintains continuous cover forestry and an uneven-aged structure (Appleton and Meyer, 2014), and its non-intensive forms can be considered as close-to-nature forestry; it does, however, require a highly skilled work force.

5.3 Mediterranean forests

In Mediterranean forests, a change in thinning regimes (density management) to earlier and more intensive thinning to improve water use efficiency of trees has the potential to lessen drought stress, fire risk and vulnerability to insects (Chmura *et al.*, 2011; Giuggiola *et al.*, 2013). Priorities in Mediterranean countries are thus likely to differ from those in other regions (an example from Portugal is shown in Box 9). Fire and pest management with an intensive pest- and disease-monitoring system is an important part of an integrated forest management and adaptation strategy in Central and Southern Europe. In Portugal, France and Spain, fire management using prescribed burning to reduce fuel availability together with other fire-suppression practices are applied under specific legal frameworks (Portugal and France) with specialised teams and a national system for professional accreditation. 'Clean management' and early salvage cuttings after storm damage can also diminish the risk of large-scale bark beetle outbreaks, although such measures run counter to the need to increase deadwood pools in support of biodiversity targets. Bolte *et al.* (2009) have proposed an integrative management approach that would combine species suitability tests and larger-scale modelling, with priority mapping of adaptation strategies at the national, regional and local scales. However, the lack of harmonised data is currently a major obstacle for implementing such an approach.

In summary, although the forests in different parts of Europe are historically very different, analyses lead to a common conclusion that their future resilience would be improved by maintaining and improving forest variability, which includes mixed-species forests and genetic diversity, and using varying silvicultural methods. To meet the objectives of the Paris Agreement, rapid and firm actions to sustain or increase forest carbon stocks are required, and the same applies for biodiversity targets. In Northern European forests, intensive management practices aiming to produce wood may compromise the potential that exists for increasing forest carbon storage and simultaneously their biodiversity. Including the values of carbon flows and pools requires increases in planting density, reducing intermediate thinning and implementing longer rotation periods than in traditional silviculture. Selecting tree species that are adapted to the local conditions, changing thinning regimes or shortening rotation periods may be beneficial for preventing fire and storm damage in parts of Central European and Mediterranean forests, although the last two may have a negative impact on biodiversity.

6 Conclusions

This report has been compiled from the perspective that society places many demands on forests, which can rarely all be achieved from the same forests at the same time. Conflicting demands imply the need for choices to be made. These include choices that can be managed through economic supply and demand; for instance, determining the balance of supply between saw logs and feedstock for a biorefinery. However, conflicts and trade-offs between different forest functions are more difficult to manage—especially when traditional markets do not attach a value or provide incentives to manage them. In particular, these shortcomings are relevant to ecosystem services including climate regulation and biodiversity. The aim of this report has been to explore evidence of trade-offs and synergies between the different functions and services offered by forests, and support policy-makers and others in developing policies that are consistent with sustainable and multi-functional use of the EU's forests.

The EU Forest Strategy (2014/2223(INI)) adopts the subsidiarity principle and confirms that '*the competence of the Member States in this area must be respected*'. This strategy reflects the long history of local forest management described in Chapter 1, but the issues focused on in this report extend beyond national borders, straddle the EU, and cannot all be solved through uncoordinated national measures alone. In particular, global issues such as climate change and biodiversity decline demand stronger coherence, joint strategies and management measures, where national policy targets and actions need to be consistent with European and global targets. As is highlighted in Chapter 5, national policies attach different priorities to the various forestry functions, and there are examples where increased use of forestry resource will reduce the carbon stock in the short term, while others are seeking to increase carbon stocks. The pan-European and global nature of some of the EU's commitments require a high degree of coherence between EU and Member State policies.

One notable characteristic of European forests is that they are growing with an annual increment of wood amounting to 720 million m^3 (Forest Europe, 2015). However, this growth is interpreted very differently by different stakeholders. On the one hand, some see the increment as a substantial contribution to Europe's efforts to mitigate climate change and the increased carbon stock as not only needing to be protected but enhanced further. Others see it as a resource which should be better used. Resolving such conflicting viewpoints and special interests places a particular challenge on European policy-makers, and EASAC hopes this report may contribute to the associated policy debate.

This is, however, against the background that the effects of climate change on European forests are already being seen, while the EEA (2017) concludes that the relative importance of climate change as a major driver of biodiversity and ecosystem change is likely to increase further in the future. In addition to the direct impacts of changing climate, human efforts to mitigate and adapt to it can both positively and negatively affect biodiversity and other ecosystem services, so that new forest management tools are required to adapt to changing conditions and to maintain the sustainable functioning of forests.

Before considering specific policy options, policy-makers need to recognise that the timescales involved in forest management and its impact on the environment are long—often exceeding 100 years. Today's mature forests were planted decades ago; equally, what we do with forests today will be influencing ecosystems and society for decades into the future. Changes in policies that are expected to have a large-scale impact on European forests should therefore be carefully considered, as it may take a long time before their full impacts become evident. For example, it may be possible to increase timber output quickly through harvesting some of the remaining old-growth forests, but reversing that would take more than a century and, in the case of endangered species, the consequences may be irreversible. For such reasons, it is important to reflect the multi-functionality of forests both in national and in European policies.

The principles of SFM applied in the EU recognise the multi-functionality of forests. SFM aims to maintain the ecological functions of forests and their ecosystem services while fulfilling the economic and social functions that provide many benefits, including a mix of wood-based products and services that provide opportunities for rural job creation, not only in industries making forest products, but also in other forest-related activities and businesses such as tourism. Our analyses do, however, show tensions between some of the six criteria for SFM (see Box 2). One example is between demands for increased extraction of biomass from forests (criterion 3) and the contributions made by the same biomass *in situ* to criteria 2, 4 and 5 (soil fertility, biodiversity and protective functions). Other synergies and trade-offs exist in the way in which forests' interaction with climate change mitigation is managed (criterion 1), and synergies through more diverse ecosystems being more efficient in providing climate change mitigation (criteria 1, 3 and 4). In the latter context, policy options such as logging residue removal, conversion of tree species (native or introduced, exotic) or changed rotation times will often be in conflict with biodiversity goals in

traditionally managed production forests (Moen *et al.*, 2014; Felton *et al.*, 2016). Forest managers faced with such decisions should take into account the important role of biodiversity in the resilience, regulation and multi-functionality of forests (Van der Plas *et al.*, 2016a, 2016b).

Critical issues and messages to emerge from the previous chapters are summarised below.

On forest management

- Adaptive management to strengthen resilience to climate change should prioritise less susceptible species, ensure genetic diversity to increase resilience, and design forest regeneration and harvesting schemes to take into account new risks. Transforming single-species stands to mixed stands will probably provide greater vitality and resistance against abiotic and biotic disturbances (for example diseases, pests, fires and storms).

- Private forest owners increasingly recognise the multiple use of forests: not just as a source for timber or other raw materials, but also as sources for recreation, conservation of biodiversity, landscape elements as well as climate change mitigation. This is generating a need for a new diversified forest management approach that potentially conflicts with policies that intensify the use of forests for the provision of raw materials.

On forests and biodiversity

- The role of forests is particularly important for biodiversity. The main threat for endangered forest-dwelling species is the limited amount and highly fragmented nature of the remaining natural forests; protection of the current conservation areas should thus be maintained (land sparing) and combined with land sharing in multi-use landscapes to strengthen conservation activities.

- Meeting the targets in the CBD requires coordination between Member States to coordinate national decisions on protected areas. For example, in support of biodiversity objectives, 'corridors' might be established between forest areas in different countries to meet the needs of specific species. Forest management has a crucial influence on species living in forests. Maintaining/improving biodiversity requires both the protection of remaining old-growth and ancient forests, and increases in the amounts of deadwood and other structural elements in managed forests. Negative ecological impacts of management can be avoided by appropriate multi-scale planning and the introduction of new instruments such as payments for ecosystem services. Existing models in some countries should be evaluated for their potential application in a wider European context (Farley *et al.*, 2010).

- Management should recognise that biodiversity underpins the ecosystem services of forests and is linked to their productivity. A decline in biodiversity threatens the ability of both managed and natural ecosystems to adapt to changing conditions and hampers the provisioning of ecosystem services. We can identify several climate change adaptation and mitigation strategies, including continuous cover forestry, conversion to native broadleaf tree species, and increased rotation times, which are largely consistent with biodiversity goals, improving habitat availability in managed forests, and furthermore provide almost equal or sometimes higher revenue for forest owners (Kuuluvainen *et al.*, 2012; Felton *et al.*, 2016; Tahvonen and Rämö, 2016).

On forests and climate change mitigation

- The climate impact of forests and forestry includes both GHG effects and biophysical effects. Climate effects through albedo or influencing the hydrology cycle (including volatile organic compounds and microbes which trigger clouds) may be as important as the role of forests in carbon management. These should be taken into account in climate change mitigation actions, or there is a risk of mitigation projects that provide little climate benefit or, in the worst case, are counter-productive and costly. Extending management options to mixed evergreen–deciduous stands seems to be a low-risk diversification strategy for incorporating biophysical effects.

- The Paris COP21 targets may not be reachable without sustaining or increasing carbon storage in existing forests. There is a real danger that present policy over-emphasises the use of forests in energy production instead of increasing forest stocks for carbon storage. A more balanced and economically efficient policy is needed. The 'cleaner earns, polluter pays principle', suggesting that carbon storage (i.e. negative emissions) should be subsidised and emissions from forest bioenergy should be accounted for and controlled through appropriate means, could provide cost-effective incentives for forest management and the use of wood.

Revision of LULUCF reporting

- A critical feature in the emerging EU policy is how the future *forest reference levels* for Member States are specified. These should be set on scientifically objective grounds; otherwise there is a danger that inappropriate specification of forest reference levels will lead to emission transition between different EU categories without any real decrease in adverse

climate effects. In the worst case, such perverse transitions could be promoted by public subsidies.

Objectives of climate and energy policy (forest biomass)

- The initial proposals in the Commission's 2016 energy package (EC, 2016a) already take into account many of the core scientific issues examined in this report (see Box 6)—in particular the critical issue of payback times inherent in the concept of carbon neutrality. The extent to which these are reflected in revisions to the RED and LULUCF rules will be influenced by further debate within the European Parliament and Member States. While such debate needs to take into account a range of factors (supply security and costs among them), EASAC advocates that the most important consideration should be the overall impacts on atmospheric concentrations of GHG, and a requirement to make a positive contribution to climate change mitigation over a climate-relevant period.

On the timescales to be considered in assessing climate impacts

- The potentially very long payback periods for forest biomass raise important issues given the UNFCCC's aspiration of limiting warming to 1.5 °C above pre-industrial levels to '*significantly reduce the risks and impacts of climate change*'. On current trends, this may be exceeded in around a decade. Relying on forest biomass for the EU's renewable energy, with its associated initial increase in atmospheric carbon dioxide levels, increases the risk of overshooting the 1.5°C target if payback periods are longer than this. The European Commission should consider the extent to which large-scale forest biomass energy use is compatible with UNFCCC targets and whether a maximum allowable payback period should be set in its sustainability criteria.

Life cycle assessment for forest biomass

- To make an accurate assessment of the climate impacts of bioenergy projects, the life cycle assessment changes emerging under the 2016 revisions to the RED should include changes in the carbon stock of a forest and carbon sequestration that will be foregone as a result of forest biomass use. Expanding life cycle assessment to include carbon stock changes may also need to consider interactions between bioenergy demand and forest management. Here there is some debate on the extent to which forest owners may, with access to bioenergy markets, better protect and manage their forests and invest in forest stocks (Daigneault *et al.*, 2012).

- With substantial imports of forest biomass taking place into some Member States, allowing biomass energy emissions to be counted as 'zero' emission in the consuming country gives a false impression of that country's progress towards reducing climate forcing, since the emissions are merely shifted to another category or country. The climate impact of GHG emissions is not related to location and thus this separation lacks any significance from a climate perspective. EASAC thus welcomes the European Commission's intention that emissions of biomass used in energy will be recorded and counted towards each Member State's 2030 climate commitments, and that more robust accounting rules and governance for forest management will provide a solid basis for Europe's future post-2020 renewables policy.

Defining sustainability criteria for forest biomass

- Using forest biomass for energy requires science-based standards to avoid deleterious effects on climate, since the wide range of bioenergy scenarios includes those where burning forest biomass releases significantly more carbon dioxide per unit of electricity generated than fossil fuels over extended periods. Regulations and governance should be designed to ensure that forest biomass energy makes an effective contribution to climate change mitigation.

- EASAC supports the adoption of a cascading approach to improve the climate mitigation potential of forests and their sustainable use. Using wood in durable commodities and construction stores carbon over long periods, and substitutes for materials that have a high carbon footprint (steel, concrete, etc.). It may also be further recycled at end of life for further material or biorefinery applications before ultimately being used for energy recovery. Such cascading use offers mitigation potential and promotes greater circularity and the creation of added value (Muys *et al.*, 2014).

- EASAC concludes that scientific knowledge is sufficient to allow the general characteristics of feedstocks to be defined and to avoid the use of biomass with long payback periods. Although, historically, most forest biomass used in Europe for bioenergy has been an integrated part of forest management (scenario 1 in section 4.1) with short payback periods, expanding extraction of biomass or felling primarily for bioenergy (scenarios 2 and 3 in section 4.1) requires criteria to be applied to avoid negative effects on climate persisting for long periods. For instance, the Netherlands introduced legislation to require sustainability criteria for forest

biomass pellets[24]. The critical factor is to restrict economic incentives to cases where overall GHG emissions (including biogenic emissions) are fully accounted for and shown to contribute to climate change mitigation in a climate-relevant timescale.

On the role of biomass in renewable energy policy

- Biomass energy is significantly less effective in reducing atmospheric concentrations of carbon dioxide than other sources of renewable energy. For instance, the carbon payback time for wind and solar lies between a few months to a few years (Marimuthu and Kirubakaran, 2013), instead of the years to decades (even centuries) for forest bioenergy. Policy-makers should re-examine environmental credit rules and associated subsidies to link financial incentives to the real contribution of each technology to climate change mitigation.

[24] On 18 March 2015, the Dutch energy sector and non-governmental organisations agreed upon the sustainability criteria for biomass. On 30 March, these requirements were laid down in official Dutch legislation. Wood pellets that are used for the subsidized generation of heat or electricity must be produced in compliance with this legislation, which applies limits to the percentage of total woody biomass extracted in any given year and area, disallows conversion of (semi-natural) forests and requires evidence that carbon stocks in forests are being maintained or increased.

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Annex 2 Glossary

CBD	United Nations Convention on Biological Diversity
COP	Conference of the Parties
EEA	European Environment Agency
EFI	European Forestry Institute
ESR	Effort Sharing Regulation
EUFORGEN	European Forest Genetic Resources Programme
FAO	Food and Agriculture Organization of the United Nations
FSC	Forest Stewardship Council
GHG	Greenhouse gases
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JRC	Joint Research Centre
LULUCF	Land use, land-use change and forestry
NET	Negative emission technology
PEFC	Programme for the Endorsement of Forest Certification
RED	Renewable Energy Directive
SRC	Short rotation coppicing
SFM	Sustainable forest management
TEEB	The Economics of Ecosystems and Biodiversity
Tg	Teragram (one trillion (10^{12}) grams, equal to one million tonnes)
UNFCCC	United Nations Framework Convention on Climate Change

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Attachment 7

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LETTER • OPEN ACCESS

Does replacing coal with wood lower CO_2 emissions? Dynamic lifecycle analysis of wood bioenergy

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LETTER

Does replacing coal with wood lower CO_2 emissions? Dynamic lifecycle analysis of wood bioenergy

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Supplementary material for this article is available online

Abstract

Bioenergy is booming as nations seek to cut their greenhouse gas emissions. The European Union declared biofuels to be carbon-neutral, triggering a surge in wood use. But do biofuels actually reduce emissions? A molecule of CO_2 emitted today has the same impact on radiative forcing whether it comes from coal or biomass. Biofuels can only reduce atmospheric CO_2 over time through post-harvest increases in net primary production (NPP). The climate impact of biofuels therefore depends on CO_2 emissions from combustion of biofuels versus fossil fuels, the fate of the harvested land and dynamics of NPP. Here we develop a model for dynamic bioenergy lifecycle analysis. The model tracks carbon stocks and fluxes among the atmosphere, biomass, and soils, is extensible to multiple land types and regions, and runs in ≈1s, enabling rapid, interactive policy design and sensitivity testing. We simulate substitution of wood for coal in power generation, estimating the parameters governing NPP and other fluxes using data for forests in the eastern US and using published estimates for supply chain emissions. Because combustion and processing efficiencies for wood are less than coal, the immediate impact of substituting wood for coal is an increase in atmospheric CO_2 relative to coal. The payback time for this carbon debt ranges from 44–104 years after clearcut, depending on forest type—assuming the land remains forest. Surprisingly, replanting hardwood forests with fast-growing pine plantations raises the CO_2 impact of wood because the equilibrium carbon density of plantations is lower than natural forests. Further, projected growth in wood harvest for bioenergy would increase atmospheric CO_2 for at least a century because new carbon debt continuously exceeds NPP. Assuming biofuels are carbon neutral may worsen irreversible impacts of climate change before benefits accrue. Instead, explicit dynamic models should be used to assess the climate impacts of biofuels.

1. Introduction

Limiting global warming to no more than 2 °C requires large, rapid cuts in fossil fuel consumption by mid-century (Figueres *et al* 2017, IPCC 2014). In response, governments around the world are promoting biomass to reduce their greenhouse gas (GHG) emissions. The European Union declared biofuels to be carbon-neutral to help meet its goal of 20% renewable energy by 2020, triggering a surge in use of wood for heat and electricity (European Commission 2003, Leturcq 2014, Stupak *et al* 2007). The United Kingdom subsidizes wood pellets for electric power generation and has become the world's largest pellet importer (Thrän *et al* 2017). The US federal government and a number of US states are considering whether to declare wood fuels carbon-neutral or to promote their use (Cornwall 2017), while at COP23 in Bonn 'China and 18 other nations representing half the world's population said…they planned to increase the use of wood...to generate energy as part of efforts to limit climate change' (Biofuture Platform 2017, Doyle and Roche 2017).

But do biofuels actually reduce GHG emissions? The appeal is intuitive: fossil fuels inject carbon sequestered in geological reservoirs for millions of years into the atmosphere, where it accumulates and causes global warming (IPCC 2013). In contrast, biofuels recycle carbon from the atmosphere, helping to keep fossil carbon in the ground (IPCC 2013).

However, a molecule of CO_2 added to the atmosphere today has the same impact on radiative forcing and warming whether it came from coal millions of years old or biomass grown last year. Biofuels can only reduce atmospheric CO_2 over time by increasing net primary production (NPP) above what it otherwise would have been (DeCicco 2013). Assessing the climate impact of wood and other biofuels therefore depends on two critical questions: first, at the point of combustion, do biofuels generate more or less CO_2 per unit of end-use energy than fossil fuels? Second, what are the dynamics of biomass (re)growth and how do NPP and carbon fluxes from biomass and soils depend on the fate of the harvested land?

Confusion over these questions has caused the scientific debate over the climate impact of bioenergy and, especially wood, to remain 'contentious' (Creutzig *et al* 2015, Ter-Mikaelian *et al* 2015). The wood industry and many governments promote wood as a renewable, carbon-neutral fuel, while many environmental groups oppose wood bioenergy because it causes deforestation, harming natural carbon sinks, ecosystems, and biodiversity (Cornwall 2017). Advocates emphasize a long time horizon to evaluate the impact of biofuels, a century or more, by which time it is assumed forests will regrow, offsetting initial emissions. Opponents point to the potential for wood energy to increase CO_2 levels in the short run, incurring a 'carbon debt' that can only be paid off slowly, and worry that the resulting increase in atmospheric CO_2 will worsen global warming and lead to irreversible impacts before the benefits of new growth can occur (Brack 2017, Buchholz *et al* 2016, Cornwall 2017).

Life cycle analysis is commonly used to answer the first question. Results vary with the assumed system boundary and biofuel harvesting, processing and transport methods (e.g. Buchholz *et al* 2016). However, although wood has approximately the same carbon intensity as coal (0.027 vs. 0.025 tC GJ^{-1} of primary energy; see supplementary material), combustion efficiency of wood and wood pellets is lower (Netherlands Enterprise Agency; IEA 2016). Estimates also suggest higher processing losses in the wood supply chain (Röder *et al* 2015). Consequently, wood-fired power plants generate more CO_2 per kWh than coal (supplementary table S5 available at stacks.iop.org/ERL/13/015007/mmedia). Burning wood instead of coal therefore creates a carbon debt—an immediate increase in atmospheric CO_2 compared to fossil energy—that can be repaid over time only as—and if— NPP rises above the flux of carbon from biomass and soils to the atmosphere on the harvested lands.

Dynamic analysis is required to answer the second question (e.g. Helin *et al* 2013). The carbon cycle and climate impacts of bioenergy involve multiple stocks of carbon (e.g. in biomass, soils and dead organic matter, and the atmosphere) and the processes that control the flow of carbon among those stocks including NPP, transfer of carbon from biomass to soil, decomposition of organic matter, consumption and respiration of carbon in biomass and soils, etc. Tools are needed to assess the dynamic climate impact of bioenergy over policy-relevant time horizons. Because of the uncertainty and debate over the impacts of biofuels, such tools should allow users to examine alternative assumptions and scenarios easily and quickly, and would avoid the need to use static summary metrics such as global warming potentials (GWP) and contentious debate over the appropriate time horizon for these approximations, e.g. whether to use GWP20 or GWP100 (Ocko *et al* 2017).

To address this need we developed an interactive decision-support model that enables policymakers and other stakeholders to explore the dynamic impact of biofuels on carbon emissions and climate. The model is fully documented, freely available, runs in about a second on ordinary laptops and is extensible to any number of land use categories and spatial scales. Users receive immediate feedback on the impacts of their scenarios and assumptions. Here we describe the model and use it to explore the dynamics of substituting wood for coal in electric power production, using wood sourced from a range of forest types in the US to estimate model parameters governing NPP and carbon fluxes.

2. Methods

2.1. Model structure

We build on the widely-used C-ROADS climate policy model (Sterman *et al* 2012, Sterman *et al* 2013), developing a more detailed representation of land use, the carbon stocks associated with different types of land and the fluxes arising from them. C-ROADS is a member of the family of simple climate models, consisting of a system of differential equations representing the carbon cycle, budgets and stocks of GHGs, radiative forcing and the heat balance of the Earth. C-ROADS closely replicates GHG concentrations, global mean surface temperature, and other climate metrics from 1850, and matches CMIP5 model projections through 2100 across a wide range of Representative Concentration Pathways (RCPs) (Knutti and Sedlacek 2013, Vuuren *et al* 2011). C-ROADS has been used by policymakers (Sterman *et al* 2012) and is freely available (www.climateinteractive.org).

The carbon cycle in the original C-ROADS model includes globally aggregated stocks of carbon in fossil fuels, the atmosphere, terrestrial biomass and soils, and a four-layer ocean. Here we disaggregate the treatment

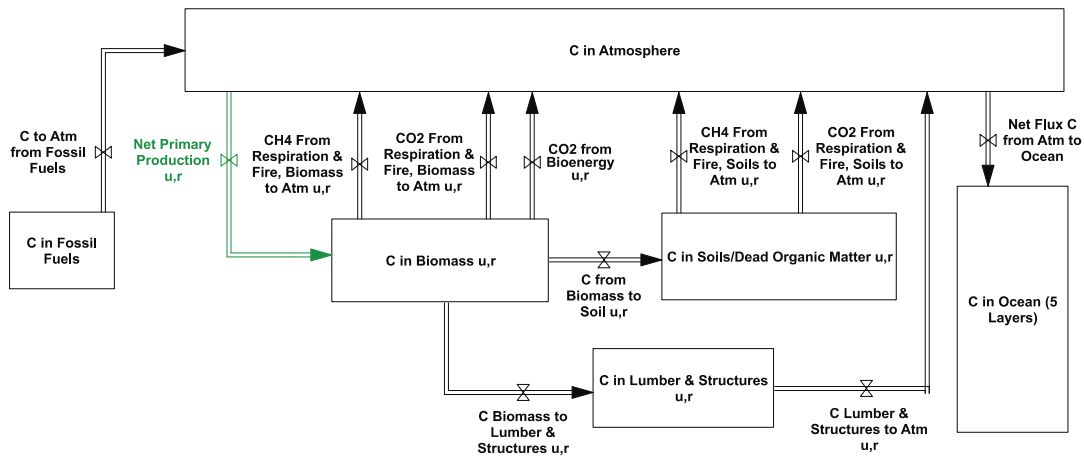

Figure 1. Modified carbon cycle in extended C-ROADS model. Carbon in biomass, soils, and structures (e.g. lumber in buildings), and fluxes among these compartments, are disaggregated by land type, *u*, and region, *r*. Carbon can flow from biomass and soils from each patch, *u*, *r*, to the atmosphere as CO_2 or CH_4. In addition, bioenergy harvest and combustion generate CO_2. CO_2 and CH_4 fluxes associated with changes in land use, e.g. from forest to pasture, cropland or developed land are included in the model but not shown here. On the policy-relevant time scale (e.g. through 2100), creation of new fossil fuels from terrestrial or oceanic carbon sources assumed to be negligible. Note: as described in the text and supplementary material, CH_4 fluxes from biomass and soils are set to zero for forest scenarios considered here to isolate the impact of bioenergy in the scenarios tested.

of terrestrial carbon stocks both geographically and by land type (e.g. forest, pasture, cropland, developed land, etc.). For each region, the model represents the area of each type of land and changes in land use resulting from natural processes and human activity, along with the carbon stocks and fluxes associated with each. The model is extensible to any number of land/land use categories and geographic areas. For example, one could configure the model to represent different types of forests, with similar disaggregation for other land types, and at geographic scales from regions to nations to, if data are available, even smaller areas.

Figure 1 shows an overview of the carbon cycle in the extended model. As in the original model, combustion of fossil fuels injects carbon into the atmosphere. Unlike the original model, carbon stocks in biomass and soil are now represented for each category of land and geographical area. The model also includes a compartment for carbon stored in lumber and structures. Consistent with reporting approaches for the IPCC, FAO, and US Forest Service (FAO 2016, Penman *et al* 2003, Smith *et al* 2006), biomass in forest land includes living trees, including stems, branches, foliage, and coarse roots in both mature and understory trees; the stock denoted 'soil carbon' includes soil organic matter, dead roots, litter (dead foliage, dead branches, etc), downed and standing dead trees, and living fine roots (Woodall *et al* 2015). Biomass is increased by net primary production. Carbon in biomass can return to the atmosphere as CO_2 or CH_4 and is transferred to the soil stock via litterfall and tree mortality. Carbon is also lost from both biomass and dead organic matter by fire. Carbon in the soil stock is transferred to the atmosphere through the activity of decomposers and other heterotrophs (Fahey *et al* 2005). The supplementary material provides full documentation.

Although the model can be configured for any number of land types and uses, here we focus on wood harvested for electricity generation. For simplicity, we configure the model to represent one region with three categories of land: unmanaged forest, recently harvested forest, and 'other,' which includes all other land use categories (cropland, pasture, developed land, etc.).

2.2. Parameter estimation

Each unit of end-use bioenergy displaces the same end-use energy generated from fossil fuels, so net CO_2 emissions from biomass at the point of combustion depend on which energy source is more efficient overall, given fuel carbon intensity, combustion efficiency, processing losses, and emissions from their supply chains. Typical combustion efficiencies for wood are approximately 25%, compared to 35% for coal (Netherlands Enterprise Agency 2011, IEA 2016). Published estimates vary with the process examined and the system boundary considered, but processing losses (in energy content) for the wood pellet supply chain are on the order of approximately 27% if biomass is used in the drying process (Röder *et al* 2015), compared to losses of approximately 11% for coal (IEA 2016). Differences in supply chain emissions from extraction/harvest, and transportation are uncertain but relatively small compared to the large differences in combustion and processing efficiencies (e.g. Odeh and Cockerill 2008, Röder *et al* 2015). Consequently, wood pellets emit approximately 0.071 tC more CO_2 per GJ of end-use energy than coal (see supplementary material).

The determinants of NPP and carbon fluxes from biomass and soil to the atmosphere are therefore critical to assessing the dynamic impact of bioenergy including the carbon debt payback period and long-run reduction in atmospheric CO_2. To estimate the parameters

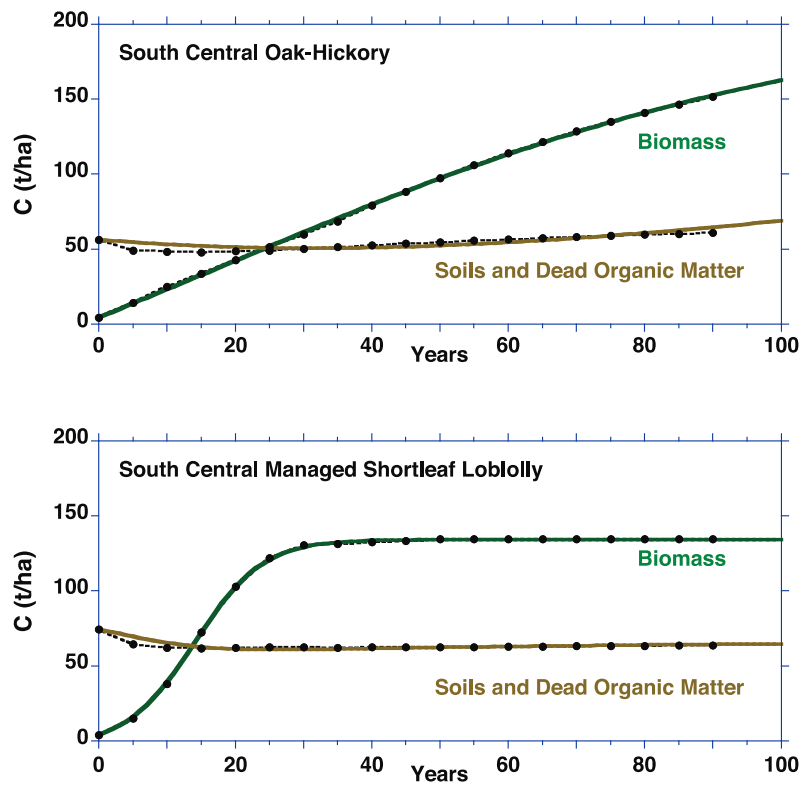

Figure 2. Growth curves showing carbon density (tC ha^{-1}) for oak–hickory (top) and managed shortleaf loblolly pine plantations (bottom) in the south-central US, comparing Smith *et al* (2006) growth curves (dashed lines with data points) to the model (solid lines), with best-fit parameters. Supplementary figure S2 and tables S2–S3 show results for all forest types estimated.

governing NPP and these fluxes we use the post-harvest growth curves in Smith *et al* (2006), which span many regions and species in US forests. To illustrate, figure 2 shows the Smith *et al* growth curves for south-central US oak–hickory forest and managed shortleaf loblolly pine plantations. The growth patterns differ markedly in both their shape and time required to reach maximum biomass. After harvest, the managed loblolly plantation regrows quickly, following a classic S-shaped curve and reaching maximum biomass after about three decades, while the hardwood forest grows roughly linearly for about 50 years and is still growing after a century. Note that in both cases, soil carbon declines for several decades after harvest because the C flux from biomass to soils is cut while heterotrophic respiration continues to release C from soils and dead organic matter to the atmosphere.

To model NPP we specify a variant of the Richards (1959) growth model, widely used in forest growth modeling. The US wood pellet industry is growing rapidly, and much of the production is exported to the EU and UK. We therefore estimate the carbon cycle parameters from growth curves for temperate US forests reported by Smith *et al* (2006). We estimate the parameters of NPP jointly with those governing fluxes of CO_2 from biomass to soil and from each compartment to the atmosphere using nonlinear least squares and Markov Chain Monte Carlo methods (supplementary material). The model fits the Smith *et al* growth curves closely: the mean absolute error relative to the mean ranges from 0.008%–0.065% for biomass and from 0.006%–0.074% for soils (figure 2, table S2).

3. Results

In the scenarios below, we adopt assumptions that favor bioenergy. Specifically, we assume bioenergy from wood pellets is used to offset coal, the most carbon intensive fossil fuel; if wood offsets power generated from natural gas its carbon debt would be much larger. Estimates of net CH_4 fluxes from forest biomass and soils are poorly constrained and considered to be insignificant in most global methane budgets (e.g. Ito and Inatomi 2012, Saunois *et al* 2016, Shoemaker *et al* 2014); we therefore assume them to be zero. We assume all land harvested for bioenergy is allowed to regrow without any fire (Buchholz *et al* 2016), erosion, disease, unplanned logging, or other ecological disturbances, including climate change impacts, that could limit regrowth or inject GHGs into the atmosphere beyond the direct impact of the bioenergy harvest. We further assume that the decline in coal use resulting from wood does not lower coal prices, increasing coal demand elsewhere, an effect estimated to be large (e.g. York 2012).

To isolate the dynamic impact of bioenergy on CO_2 emissions we run the model from an initial equilibrium

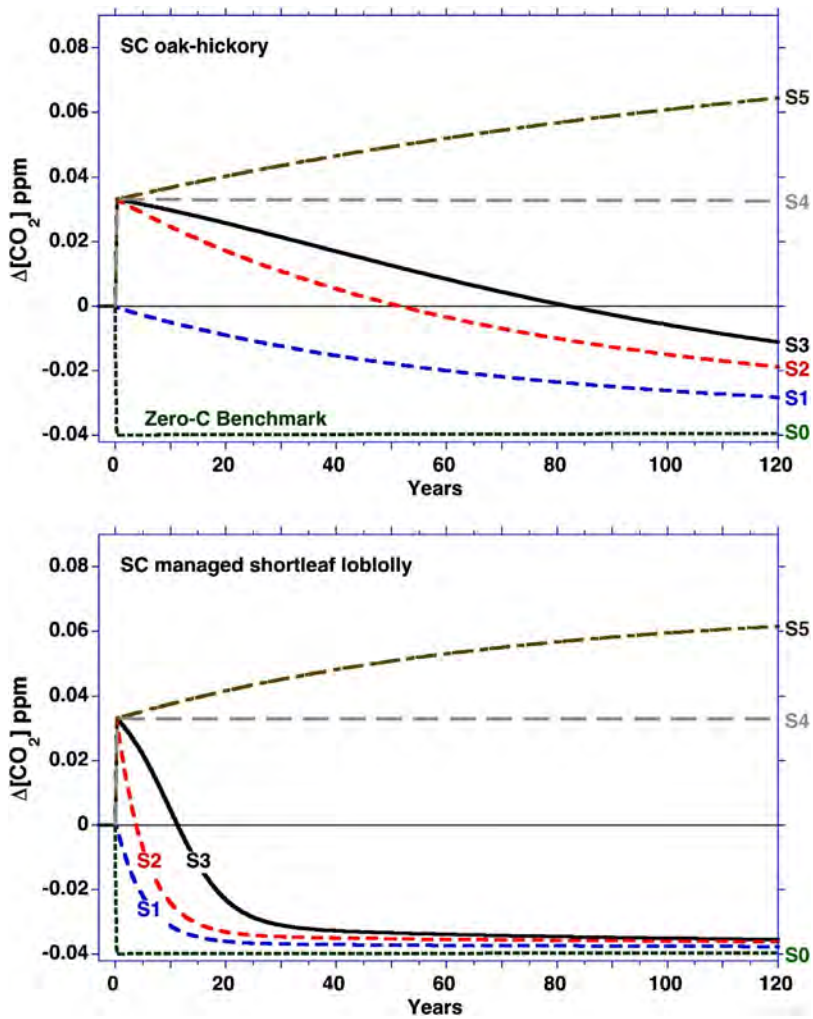

Figure 3. Change in atmospheric CO_2 concentration resulting from displacement of coal by wood. $\Delta[CO_2]$ is relative to continued coal use. All scenarios show the change in atmospheric CO_2 (ppmv) resulting from a single 1 EJ pulse of end-use energy from biomass used to displace coal in year 0. Top: south-central (SC) oak–hickory forest; bottom: SC managed shortleaf loblolly plantation. The bioenergy pulse causes an immediate increase in CO_2 concentration (the initial carbon debt) in scenarios 2–5 due to lower combustion and processing efficiencies for wood compared to coal. The year in which $\Delta[CO_2]$ falls below zero is the carbon debt payback time. Supplement figure S3 shows the results for all eight forest types examined. S0: Benchmark showing impact of 1 EJ pulse of zero carbon energy. S1: Bioenergy assumed to have the same combustion and processing efficiency as coal, and the same supply chain emissions; with 25% of biomass removed from the land harvested through thinning. S2: Actual efficiencies and supply chain emissions for wood pellets; 25% of biomass harvested through thinning. S3: S2 with 95% of biomass harvested (clear cut). S4: S3 with clear cut and no regrowth of harvested land and no C released from soil stocks. S5: S4 with C released from soil stocks at the estimated fractional rate.

in which the carbon fluxes from biomass and soils to the atmosphere are balanced by NPP, and in which net CO_2 flux to the ocean is zero throughout, identifying the impacts of bioenergy separate from other sources of disequilibrium, e.g. prior logging and marine uptake of CO_2. Including ocean CO_2 uptake would moderate increases in atmospheric CO_2 from bioenergy but worsen ocean acidification and other impacts. These effects are left for future work.

Figure 3 shows the results for a set of scenarios using parameters estimated for oak–hickory forest in the south-central US (supplementary figure S3, table S7 provide results for all eight forest types we estimated). All scenarios examine a 1 exajoule (EJ) pulse of end-use electric energy generated from wood pellets in year 0, offsetting 1 EJ of end-use electricity generated from coal (total world energy use exceeds 550 EJ yr^{-1}, US EIA 2016).

Scenario 0 provides a benchmark showing how atmospheric CO_2 would change if 1 EJ of end-use energy from coal were offset by a zero-carbon energy source, such as solar or wind (and assuming zero emissions from the supply chain). Displacing 1 EJ of end-use energy from coal with a zero C alternative keeps 0.07 GtC of fossil carbon in the ground, immediately and permanently lowering atmospheric CO_2 by approximately 0.04 ppm relative to continued coal use.

Scenario 1 simulates the counterfactual case in which bioenergy is assumed to have the same carbon emissions per EJ of end-use energy as coal, including the same combustion and processing efficiency and supply chain emissions. We assume that 25%

of the biomass is removed from each hectare of the harvested forest by thinning, not clear cutting, that the forest is allowed to regrow with no subsequent harvest, fire, disease, or other disturbances. Because emissions are counterfactually assumed to be the same as coal, there is no immediate change in atmospheric CO_2. However, as the forest grows back, carbon is gradually removed from the atmosphere to biomass and soils. After 100 years, the forest has recovered enough to lower atmospheric CO_2 by 0.026 ppm, still 34% above the zero C case.

Scenario 2 shows the realistic case with the combustion efficiency and supply chain emissions estimated for wood pellets (supplementary table S5), again assuming 25% of the biomass is harvested by thinning. Because production and combustion of wood generate more CO_2 than coal, the first impact of bioenergy use is an increase in atmospheric CO_2. Regrowth gradually transfers C from the atmosphere to biomass and soil C stocks, leading to a carbon debt payback time of 52 years; after 100 years CO_2 remains 62% above the zero C case.

Scenario 3 is the same as S2 except we now assume the land is clear cut instead of thinned, with 95% of the biomass removed. Near-complete biomass removal reflects the growing practice of harvesting whole trees and residues (branches, litter, etc) (Achat *et al* 2015). A 95% clear cut requires only 26% as much land as in S2, but the carbon debt payback time increases to 82 years; after 100 years CO_2 remains 86% above the zero C case.

Scenario 4 shows the impact of assuming that the harvested area is clear cut as in S3 but never allowed to regrow, for example, because it is developed, with the additional assumption that the flux of C from soils and dead organic matter to the atmosphere is set to zero. Without regrowth, the carbon debt is never repaid and atmospheric CO_2 remains permanently higher.

Scenario 5 is the same as S4 except the flux of C to the atmosphere from soils and dead organic matter continues at the original fractional rate. Without regrowth, there is no flux of CO_2 from the atmosphere to terrestrial biomass or soils, but continued C flux from soils to atmosphere, causing CO_2 concentrations to rise beyond the immediate impact of the bioenergy. After a century atmospheric CO_2 has risen by 0.076 ppm, 2.3 times more than the initial impact. The actual impact of converting harvested forests to other uses will likely lie between the results of Scenarios 4 and 5, but could rise further if conversion of forest to other uses increases C fluxes from soils above the values estimated from the Smith *et al* (2006) data. Such an outcome could result from disturbances to soils from, e.g. plowing, development, fire or increasing methanogenesis, all of which we assume to be zero.

In Scenario 6 (figure 4) oak–hickory forest is clear cut and replanted as a shortleaf loblolly pine managed plantation. Loblolly pine grows faster than hardwoods (figure 2), so intuitively the conversion from unmanaged hardwood forest to managed pine plantation should speed the repayment of the carbon debt. As expected, atmospheric CO_2 initially falls faster in the plantation case compared to regrowth of the oak–hickory forest. However, the concentration bottoms out after approximately 20 years and then starts to rise, exceeding the CO_2 level when the forest is allowed to regrow. The explanation lies in the different maximum carbon densities of the two forest types: loblolly plantation grows faster but reaches a lower equilibrium carbon density compared to the unmanaged forest (figure 4), with estimated equilibrium values of 130 tC ha^{-1} for loblolly plantation vs. 211 tC ha^{-1} for oak–hickory. Consequently, although plantations grow faster, they do not remove as much C from the atmosphere as was lost when the hardwood forest was harvested, even if allowed to grow to their maximum biomass and remain unharvested. In reality, plantations are thinned every few years and harvested about every decade (US Forest Service 2000), further lowering their average C density and increasing atmospheric CO_2. Furthermore, repeated harvests can degrade the productivity of the soils, lowering NPP. To compensate, managed plantations are typically fertilized several times per rotation, increasing N_2O emissions that would further worsen the climate impact of Scenario 6 (Schulze *et al* 2012).

The supplementary material reports the 95% confidence intervals (CIs) for the estimated parameters (table S4), and sensitivity analysis across the eight forest types arising from parameter uncertainty, computed by Markov Chain Monte Carlo (table S8). The 95% CIs for the carbon debt payback times vary from 74–110 years for the hardwood species under clear cut (Scenario 3) and 11.25–12 years for the managed plantations. The supplementary material also reports the long-run CO_2 reductions for Scenarios 1–5 (table S7). For Scenario 3, after 100 years CO_2 falls an average of 51% of the maximum possible reduction (the difference between the initial carbon debt and the zero-C level in Scenario 0) for the forests and 92% for the plantations.

The supplementary material also reports sensitivity analysis of combustion efficiencies and supply chain emissions. Clearly, innovation that improves the combustion and processing efficiencies of wood *relative to coal* reduces the initial carbon debt of wood and reduces the carbon debt payback time and climate impacts of wood. However, innovations that improve the efficiencies of *both* fuels yield smaller benefits. For example, combined heat and power systems offer substantially higher combustion efficiency than conventional boilers, but would still cause an initial carbon debt since the combustion and processing efficiencies of wood remain lower than coal in such systems (supplementary figures S5–6).

The wood pellet industry is expanding rapidly and many projections call for substantial growth through 2030 or beyond (IEA 2012, IRENA 2015). Scenario 7 (figure 5) shows the impact of linear growth in

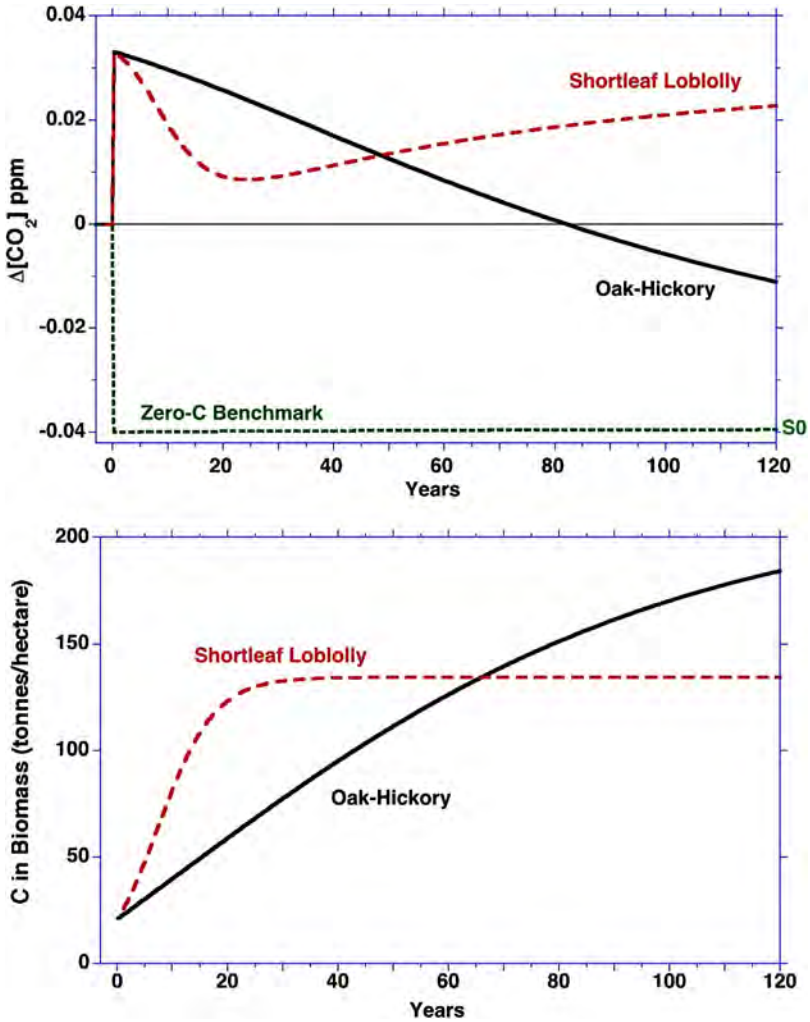

Figure 4. Scenario 6: replanting harvested oak–hickory forest after clear cut with managed plantation of shortleaf loblolly pine (south-central US), compared to allowing the oak–hickory forest to regrow (Scenario 3 in figure 2). Top: change in atmospheric CO_2 (ppmv) resulting from a single 1 EJ pulse of end-use energy from biomass used to displace coal in year. $\Delta[CO_2]$ is relative to continued coal use. Bottom: carbon in biomass (tC ha^{-1}). For the first 20 years, faster-growing loblolly pine lowers atmospheric CO_2 compared to regrowth of the oak–hickory forest, but the estimated maximum carbon density of oak–hickory forest is larger than the managed loblolly plantation (211 vs. 131 tC ha^{-1}, respectively; supplementary table S3). Consequently, the carbon debt is never repaid even if the loblolly plantation is never harvested. Due to CO_2 flux from soils, atmospheric CO_2 rises after approximately 20 years, exceeding the level from regrowth of oak–hickory after approximately 50 years.

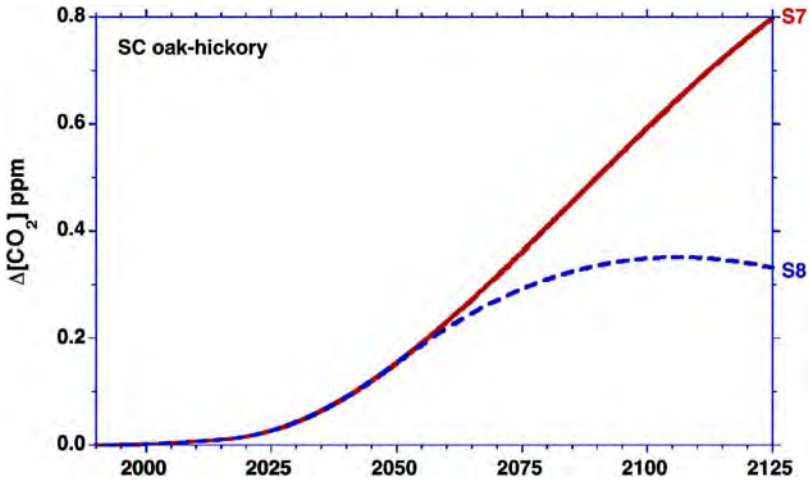

Figure 5. Change in atmospheric CO_2 concentration resulting from growth in end-use energy supplied by wood, displacing coal. $\Delta[CO_2]$ is relative to continued coal use. Scenario 7 (solid line): linear growth in end-use energy supplied by US wood pellet production, from the 2016 value of 0.028 EJ to 0.28 EJ yr^{-1} by 2050 and continuing linearly thereafter. Parameters estimated for south-central US oak–hickory forest, with harvest by clearcut. Scenario 8 (dashed line): the same as S7 except growth in end-use energy supplied by wood ceases in 2050. Supplementary figure S4 reports results for all forest types considered.

end-use bioenergy; Scenario 8 is the same except growth ceases in 2050. Growth in wood supply causes steady growth in atmospheric CO_2 because more CO_2 is added to the atmosphere every year in initial carbon debt than is paid back by regrowth, worsening global warming and climate change. The qualitative result that growth in bioenergy raises atmospheric CO_2 does not depend on the parameters: as long as bioenergy generates an initial carbon debt, increasing harvests mean more is 'borrowed' every year than is paid back. More precisely, atmospheric CO_2 rises as long as NPP remains below the initial carbon debt incurred each year plus the fluxes of carbon from biomass and soils to the atmosphere. Note further that in Scenario 8, CO_2 continues to rise for 56 years after bioenergy production growth stops and only falls below initial levels 144 years after growth stops. Results for the other forest types are similar (supplementary figure S4).

4. Discussion and conclusion

We extended the carbon cycle model in the C-ROADS climate policy model to account for different land and land use types, by region. The model explicitly treats stocks of carbon in fossil fuels, biomass, soils and dead organic matter, the atmosphere, and the fluxes among them including combustion, supply chain emissions, and regrowth of harvested lands. The model is extensible to any number of land types and uses, and geographic scales. To demonstrate the approach, we analyzed the dynamic impact of displacing coal with wood in electricity production, finding:

First, yet contrary to the policies of the EU and other nations, biomass used to displace fossil fuels injects CO_2 into the atmosphere at the point of combustion and during harvest, processing and transport. Reductions in atmospheric CO_2 come only later, and only if the harvested land is allowed to regrow.

Second, the combustion and processing efficiencies of wood in electricity generation are lower than for coal (supplementary material). Consequently, the first impact of displacing coal with wood is an increase in atmospheric CO_2 relative to continued coal use, creating an initial carbon debt.

Third, after the carbon debt is repaid, atmospheric CO_2 is lower, showing the potential long-run benefits of bioenergy. However, before breakeven, atmospheric CO_2 is higher than it would have been without the use of bioenergy, increasing radiative forcing and global average temperatures, worsening climate change, including potentially irreversible impacts that may arise before the long-run benefits are realized.

Fourth, biofuels are only beneficial in the long run if the harvested land is allowed to regrow to its pre-harvest biomass and maintained there. Natural forests have high carbon density compared to pasture, cropland, developed land and managed tree plantations. The carbon debt incurred when wood displaces coal may never be repaid if development, unplanned logging, erosion or increases in extreme temperatures, fire, and disease (all worsened by global warming) limit regrowth or accelerate the flux of carbon from soils to the atmosphere. Further, lower coal prices caused by the drop in power sector demand may stimulate coal use elsewhere, offsetting even the potential long-run benefits of bioenergy (e.g. York 2012).

Fifth, counter to intuition, harvesting existing forests and replanting with fast-growing species in managed plantations can worsen the climate impact of wood biofuel. Although managed loblolly pine grows faster than hardwood, speeding the initial recovery of forest biomass, the equilibrium carbon density of managed plantations is lower than unmanaged forest, so carbon sequestered in plantations never offsets the carbon taken from the original forest. This is true even if the managed plantation is never reharvested, and worse if the plantation is periodically reharvested. Further, typical plantations require periodic fertilization, increasing N_2O emissions and worsening their climate impact beyond what we report here (Schulze *et al* 2012).

Sixth, growth in wood harvest for bioenergy causes a steady increase in atmospheric CO_2 because the initial carbon debt incurred each year exceeds what is repaid. With the US forest parameters used here, growth in the wood pellet industry to displace coal aggravates global warming at least through the end of this century, even if the industry stops growing by 2050.

Seventh, using wood in electricity generation worsens climate change for decades or more even though many of our assumptions favor wood, including: wood displaces coal (the most carbon intensive fossil fuel); all harvested land is allowed to regrow as forest with no subsequent conversion to pasture, cropland, development or other uses; no subsequent harvest, fire or disease; no increase in coal demand resulting from lower prices induced by the decline in coal use for electric power; no increase in N_2O from fertilization of managed plantations; and no increase in CO_2 emissions or methanogenesis from disturbed land. Relaxing any of these assumptions worsens the climate impact of wood bioenergy.

In sum, although bioenergy from wood can lower long-run CO_2 concentrations compared to fossil fuels, its first impact is an increase in CO_2, worsening global warming over the critical period through 2100 even if the wood offsets coal, the most carbon-intensive fossil fuel. Declaring that biofuels are carbon neutral as the EU and others have done, erroneously assumes forest regrowth quickly and fully offsets the emissions from biofuel production and combustion. The neutrality assumption is not valid because it ignores the transient, but decades to centuries long, increase in CO_2 caused by biofuels.

Methodologically, we demonstrate the feasibility of integrating static life cycle considerations around the efficiencies of and emissions from biofuels with

explicit modeling of biomass dynamics in a model that runs fast enough to enable policymakers and other stakeholders to design and test their own scenarios. Future work will integrate the model into full climate models such as C-ROADS, creating a fast, interactive simulator that can model the impacts of different biofuel technologies and scenarios on CO_2 concentrations, radiative forcing, warming, ocean acidification, sea level rise and other impacts.

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Attachment 8

LETTER FROM SCIENTISTS TO THE EU PARLIAMENT REGARDING FOREST BIOMASS

(updated January 14, 2018)

To Members of the European Parliament,

As the European Parliament commendably moves to expand the renewable energy directive, we strongly urge members of Parliament to amend the present directive to avoid expansive harm to the world's forests and the acceleration of climate change. The flaw in the directive lies in provisions that would let countries, power plants and factories claim credit toward renewable energy targets for deliberately cutting down trees to burn them for energy. The solution should be to restrict the forest biomass eligible under the directive to residues and wastes.

For decades, European producers of paper and timber products have generated electricity and heat as beneficial by-products using wood wastes and limited forest residues. Since most of these waste materials would decompose and release carbon dioxide within a few years, using them to displace fossil fuels can reduce net carbon dioxide emissions to the atmosphere in a few years as well. By contrast, cutting down trees for bioenergy releases carbon that would otherwise stay locked up in forests, and diverting wood otherwise used for wood products will cause more cutting elsewhere to replace them.

Even if forests are allowed to regrow, using wood deliberately harvested for burning will increase carbon in the atmosphere and warming for decades to centuries – as many studies have shown – even when wood replaces coal, oil or natural gas. The reasons are fundamental and occur regardless of whether forest management is "sustainable." Burning wood is inefficient and therefore emits far more carbon than burning fossil fuels for each kilowatt hour of electricity produced. Harvesting wood also properly leaves some biomass behind to protect soils, such as roots and small branches, which decompose and emit carbon. The result is a large "carbon debt." Re-growing trees and displacement of fossil fuels may eventually pay off this "carbon debt' but only over long periods. Overall, allowing the harvest and burning of wood under the directive will transform large reductions otherwise achieved through solar and wind into large increases in carbon in the atmosphere by 2050.

Time matters. Placing an additional carbon load in the atmosphere for decades means permanent damages due to more rapid melting of glaciers and thawing of permafrost, and more packing of heat and acidity into the world's oceans. At a critical moment when countries need to be "buying time" against climate change, this approach amounts to "selling" the world's limited time to combat it.

The adverse implications not just for carbon but for global forests and biodiversity are also large. More than 100% of Europe's annual harvest of wood would be needed to supply just one third of the expanded renewable energy directive. Because demand for wood and paper will remain, the result will be increased degradation of forests around the world. The example Europe would set for other countries would be even more dangerous. Europe has been properly encouraging countries such as Indonesia and Brazil to protect their forests,

but the message of this directive is “cut your forests so long as someone burns them for energy.” Once countries invest in such efforts, fixing the error may become impossible. If the world moves to supply just an additional 3% of global energy with wood, it must double its commercial cuttings of the world’s forests.

By 1850, the use of wood for bioenergy helped drive the near deforestation of western Europe even when Europeans consumed far less energy than they do today. Although coal helped to save the forests of Europe, the solution to replacing coal is not to go back to burning forests, but instead to replace fossil fuels with low carbon sources, such as solar and wind. We urge European legislators to amend the present directive to restrict eligible forest biomass to appropriately defined residues and wastes because the fates of much of the world’s forests and the climate are literally at stake.

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Attachment 9

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Not carbon neutral: Assessing the net emissions impact of residues burned for bioenergy

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LETTER

Not carbon neutral: Assessing the net emissions impact of residues burned for bioenergy

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Keywords: bioenergy, wood pellets, climate mitigation, residues, biomass, forest residues, carbon accounting

Abstract

Climate mitigation requires emissions to peak then decline within two decades, but many mitigation models include 100 EJ or more of bioenergy, ignoring emissions from biomass oxidation. Treatment of bioenergy as 'low carbon' or carbon neutral often assumes fuels are agricultural or forestry residues that will decompose and emit CO_2 if not burned for energy. However, for 'low carbon' assumptions about residues to be reasonable, two conditions must be met: biomass must genuinely be material left over from some other process; and cumulative net emissions, the additional CO_2 emitted by burning biomass compared to its alternative fate, must be low or negligible in a timeframe meaningful for climate mitigation. This study assesses biomass use and net emissions from the US bioenergy and wood pellet manufacturing sectors. It defines the ratio of cumulative net emissions to combustion, manufacturing and transport emissions as the net emissions impact (NEI), and evaluates the NEI at year 10 and beyond for a variety of scenarios. The analysis indicates the US industrial bioenergy sector mostly burns black liquor and has an NEI of 20% at year 10, while the NEI for plants burning forest residues ranges from 41%–95%. Wood pellets have a NEI of 55%–79% at year 10, with net CO_2 emissions of 14–20 tonnes for every tonne of pellets; by year 40, the NEI is 26%–54%. Net emissions may be ten times higher at year 40 if whole trees are harvested for feedstock. Projected global pellet use would generate around 1% of world bioenergy with cumulative net emissions of 2 Gt of CO_2 by 2050. Using the NEI to weight biogenic CO_2 for inclusion in carbon trading programs and to qualify bioenergy for renewable energy subsidies would reduce emissions more effectively than the current assumption of carbon neutrality.

Introduction

Meeting the Paris Agreement goal of limiting global temperature increase will require fast deployment of zero-emissions energy and greatly increased carbon sequestration. In developing pathways to limit atmospheric CO_2, many climate mitigation models include a doubling or more of bioenergy to at least 100 EJ in the coming decades [1–3], with much of the fuel assumed to come from forestry and agricultural residues [3]. Though oxidizing 100 EJ of biomass would emit about 9 Gt of CO_2 each year, most mitigation models assign bioenergy zero net emissions.

The assumption of bioenergy carbon neutrality underpins many renewable energy investments, including in the EU, UK and Asia where dried wood pellets are imported as a replacement for coal. Such policies, and the lucrative subsidies they provide, have driven rapid growth in the wood pellet sector in North America, with US exports growing from less than 0.1 Mt in 2008 [4] to 4.9 Mt in 2016 [5]. Canadian pellet exports increased 46% from 2015–2016 [6], and US pellet exports are projected to double or triple from 2016 levels by 2025 [5, 7].

Biomass power plants tend to emit more CO_2 than fossil fueled plants per MWh, and as shown by a number of studies, net emissions from bioenergy can exceed emissions from fossil fuels for decades [8–12]. Nevertheless, some studies conclude rapid carbon benefits from burning wood pellets by employing various assumptions: that forest planting will increase in response to demand for wood [13]; that

replanting occurs immediately after harvest [14]; or that forest growth elsewhere compensates for emissions from harvesting and combusting trees [15, 16] (for a review, see Ter-Mikaelian *et al* 2015 [17]). Some discussions of bioenergy in mitigation modeling include similar assumptions that burning 'sustainable,' 'optimal' [1, 3] or 'surplus' [18] forest wood can reduce net CO_2 emissions as long as forest carbon stocks are increasing. Such assumptions often disregard the role of the forest carbon sink, thus the controversy around bioenergy carbon accounting continues.

However, on one aspect of bioenergy carbon accounting there is wide agreement: that when biomass is sourced from residues from forestry, wood products manufacturing, or agriculture, net carbon emissions are properly assessed as the difference between emissions from their use as fuel (which can include emissions from fuel manufacturing and transport), and emissions from an alternative fate, such as leaving material on-site to decompose or burning it without energy recovery [8–10, 12 19–23].

Studies using this approach generally conclude net bioenergy emissions are not zero over varying periods of time. Nonetheless, many policies still treat bioenergy as having zero or negligible emissions. European Commission guidance for the EU carbon trading program explains bioenergy emissions should be 'taken to be zero,' and that wood pellets consist of 'processing residues from forest based industries' [24]. The IPCC acknowledges harvesting trees for fuel can increase cumulative emissions for years to centuries, but concludes that 'agricultural and forestry residues can provide low-carbon and low-cost feedstock for bioenergy' [3]. The IPCC renewable energy report identifies potential for 100 EJ of bioenergy specifically from residues [18] and does not discuss potential emissions.

For the assumption that residues have negligible net emissions to be reasonable, at least two conditions must be met. First, biomass classified as residues must actually be residues—that is, materials generated by some other process, where the alternative fate is decomposition or burning without energy recovery. Second, net emissions from bioenergy, that is, the cumulative additional CO_2 emitted from processing and burning biomass versus from an alternative fate, must be low, if not negligible, within a timeframe meaningful for climate mitigation.

What should 'low net emissions in a meaningful timeframe' mean? Most scenarios for climate change mitigation that constrain temperature rise consistent with Paris Agreement goals require emissions to peak between 2020 and 2030 and decline to less than half 2010 levels by 2050 [25], with negative emissions shortly thereafter. Actions that reduce or end emissions in the next ten years are thus essential, given that elevated CO_2 is already driving essentially irreversible polar ice loss, permafrost melting, and ocean acidification, along with thermal sea-level rise, which has been shown to respond to temperature changes from short-lived climate pollutants in a ten-year timeframe [26].

Here, 'low net emissions' from bioenergy implies a comparison to gross or 'direct' emissions from manufacturing and burning biomass. This study uses a simple model to calculate a new metric, the 'net emissions impact' (NEI), which is the ratio of cumulative net emissions to direct emissions from burning residues for energy. The NEI expresses the proportion of direct CO_2 emissions that contributes an additional warming effect over a fifty-year period. Fuel and feedstock use, net emissions and the NEI are calculated for three main case studies: the existing US bioenergy sector, new wood-burning plants using chipped wood, and wood pellets that are exported to the EU to be burned as a replacement for coal.

Approach

Built in Excel, the model calculates cumulative net emissions as cumulative direct emissions (CO_2 from combustion for energy plus CO_2 from harvesting, producing, and transporting biomass, or 'HPT emissions'), minus cumulative counterfactual emissions (what emissions would be if the biomass were left in the field to decompose or were burned without energy recovery). The net emissions impact (NEI) is the ratio of cumulative net emissions to cumulative direct emissions.

HPT emissions are calculated as explained below. Direct combustion emissions are calculated as joules of heat input for each fuel multiplied by fuel-specific CO_2 emission factors [27] (non-CO_2 greenhouse gas emissions are not included in this version of the model). The spreadsheet sums cumulative counterfactual emissions from biomass collected in each year in columns, then sums across columns to calculate cumulative emissions by each year from all biomass collections up to and including that year.

Counterfactual carbon emissions (with conversion to CO_2 at the last step) are calculated as:

$$\mathrm{PE}'(t) = 1 - (e^{-k't}) \tag{1}$$

$$\mathrm{cE}'(t) = \mathrm{BC}' * \mathrm{PE}'(t) \tag{2}$$

$$\mathrm{CE}(t) = \sum_{1}^{t} \mathrm{cE}'(t) \tag{3}$$

where

$\mathrm{PE}'(t)$ = proportion of carbon from biomass collected in a given year that has been emitted by year t

k' = rate-constant for decomposition of biomass collected in a given year

$\mathrm{cE}'(t)$ = carbon from biomass collected in a given year that has been emitted by year t

BC' = carbon content of biomass collected in a given year

$\mathrm{CE}(t)$ = carbon emitted by year t from biomass collected in all years

Table 1. Model inputs for biomass burned for energy in the US. Heat input is average summed value per year for the industrial and non-industrial sectors, 2001–2016. See text for details.

Fuel	GJ yr^{-1}	CO_2 EF	HPT factor	Alternative fate	k
Agricultural biomass	31.7	0.101	7.5%	Decomposition	0.65
This constitutes a small percentage of biomass burned in the US, but can represent a large variety of materials, including crop stover, nut hulls, and sugarcane bagasse. The *k*-constant produces a half-life for residues of one year.					
Black liquor	800.5	0.087	—	Burn w/o ER	—
This is a high moisture content material left residue of pulp- and paper-making. The model assumes no net emissions from burning it for energy.					
Other biomass solids	18.3	0.101	4%	Burn w/o ER	—
EIA does not specify what these materials are. While there are likely processing costs, the model assumes a minimal 4% HPT emissions to be conservative.					
Sludge waste	6.3	0.072	—	Burn w/o ER	—
Sludge waste is another residue of pulp- and paper-making.					
Wood liquor	11.3	0.072	—	Burn w/o ER	—
This material is related to black liquor.					
Wood solids	548.8	0.081	4%	Decomposition	0.083
This includes forestry wood, mill residues, urban tree trimmings, and construction and demolition wood. For consistency with wood pellet scenarios below, the *k*-constant is 0.083.					

To evaluate emissions from the US bioenergy industry, the model uses bioenergy data from the Energy Information Administration (EIA) for 2001–2016 [28] and CO_2 combustion emission factors used by the US Environmental Protection Agency (EPA) for power sector modeling (original units short tons $mmbtu^{-1}$; converted here to metric tonnes GJ^{-1}) [27]. Alternative fate emissions are calculated using *k*-constants particular to each fuel (table 1).

The model includes HPT emissions for forestry residues and other wood as equivalent to 4% of the carbon content of green chips, based on Domke *et al* (2012) and reviews of other studies [9, 29]. The model assumes the alternative fate for agricultural residues is decomposition, as crop burning occurs on less than 1% of agricultural acres in the US [30]. Selecting an HPT factor for agricultural residues is not straightforward, as emissions from harvest, transport, shredding, baling, and sometimes pelletizing can be significant. Depending on how system boundaries are drawn, emissions from crop cultivation, including N_2O from fertilizers, can be ascribed to residues [31]. Storage also imposes lifecycle emissions because agricultural materials can only be collected at fixed intervals. Most importantly, removing agricultural residues can deplete soil carbon [32]; some estimates of total HPT emissions including soil C loss sum to more than 100% of fuel carbon content [31]. This model used an HPT factor of 7.5% for agricultural residues based solely on harvest and transport estimates for corn stover in Whitman *et al* (2011) and did not include soil carbon impacts because this factor was not included for forestry residues. As agricultural residues provided a small percentage of total fuels, the choice of HPT factor had only a trace effect, but any study of large-scale use of agricultural residues should include soil carbon effects.

Data on wood use by the US pellet manufacturing sector was obtained from the forest-industry tracking company Forisk [33]. Five pellet scenarios were modeled to examine how the *k*-constant and changing use through time affect net emissions (details in table 2). Scenarios 1–4 estimated HPT emissions (which include harvesting, transport to plant, debarking, chipping, pulverization, pellet extrusion, drying, and oversea transport) as 322 kg CO_2 per tonne of pellets, following Jonker *et al* [15], similar to an estimate by Dwivedi *et al* [14]. Also following Jonker *et al* the model assumed that pellet drying consumes 0.51 green tonnes of residues per tonne of pellets, an estimate confirmed by checking the dryer fuel to pellet production ratio in permits for two industrial-scale plants in the US [34, 35]. The model assumed residues burned to dry pellets would decompose with a *k*-constant of 0.15 if not burned for energy. Facilities that use fossil fuels to dry pellets have much higher HPT emissions [36], but this effect was not included.

Results and discussion

Sources of biomass burned for heat and power in the US

The US bioenergy sector can be divided into industrial plants, which mostly burn black liquor and wood to generate onsite heat and power for paper and wood products manufacturing, and non-industrial plants, which mostly burn wood to generate power for the electrical grid (figure 1). The industrial sector mostly utilizes biomass for heat; on average, just 21% of fuel energy was used for electricity generation from 2001–2016, while the smaller non-industrial sector allocated 87% of fuel energy to electricity generation [28].

Combined, industrial and non-industrial facilities burning biomass generated less than 1% of total electricity in the US in 2016 [37]. However, average annual generation over a three-year period in the non-industrial sector increased 62% from 2001–2003 to 2014–2016, while electricity generation stayed relatively constant in the industrial sector.

Table 2. Five scenarios for wood pellet manufacturing and use.

Scenario	10 years (2020)			25 years (2035)			40 years (2050)		
	Direct CO_2 (t)	Net CO_2 (t)	NEI	Direct CO_2 (t)	Net CO_2 (t)	NEI	Direct CO_2 (t)	Net CO_2 (t)	NEI
1: 1 tonne pellets yr^{-1}, $k = 0.15$	25	14	55%	62	21	34%	99	26	26%
2: 1 tonne pellets yr^{-1}, $k = 0.03$	25	20	79%	62	40	64%	99	54	54%
	Direct CO_2 (Gt)	Net CO_2 (Gt)	NEI	Direct CO_2 (Gt)	Net CO_2 (Gt)	NEI	Direct CO_2 (Gt)	Net CO_2 (Gt)	NEI
3: Actual US exports to year 7 (2017); modeled 15% yr^{-1} increase to 12.8 Mt yr^{-1} at year 15 (2025); continue at that level; $k = 0.083$	0.09	0.07	73%	0.53	0.28	53%	1.01	0.40	39%
4: Like Scenario 4, but cease use at year 20 (2030); $k = 0.083$	0.09	0.07	73%	0.37	0.16	43%	0.37	0.08	21%
5: Actual global demand of 13 Mt tonne pellets yr^{-1}, increasing to 28.2 Mt at yr 6 (2016); modeled increase to 66.4 Mt yr^{-1} at year 15 (2025); continue at that level; $k = 0.083$	0.63	0.44	71%	2.92	1.48	51%	5.35	1.99	32%

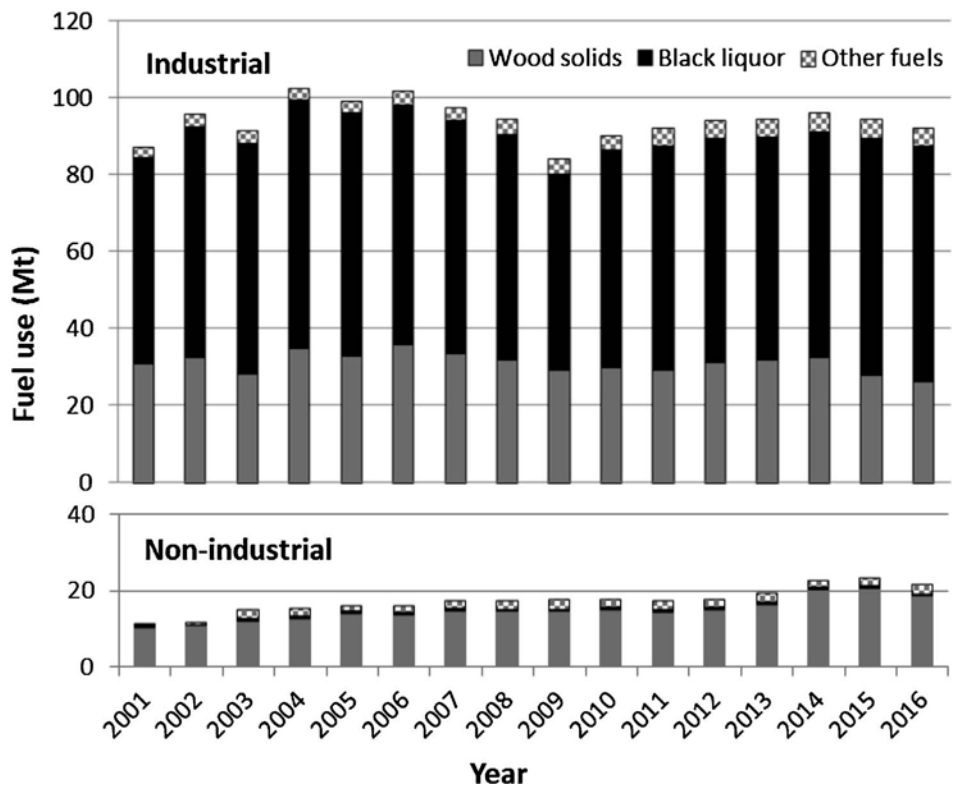

Figure 1. Fuels burned by the US industrial and non-industrial bioenergy sectors, 2001–2016 [28]. Wood burning for electricity generation in the non-industrial sector increased by about 60% from the beginning of the period.

The dominance of black liquor as fuel for industrial bioenergy means that many facilities at least partially meet the first of the low carbon conditions—that fuels genuinely be residues of some other process. However, the provenance is less clear for wood burned by the industrial and non-industrial sectors, which totaled 45 Mt (green) in 2016 [28]. Forisk estimates wood use by US biomass facilities at 35 Mt (green), a figure that omits certain large industrial users reported by the EIA, and reported as of late 2016 that operating and under-construction plants were burning pulpwood (7.4%); 'dirty chips/forest residues' (49.6%); urban wood (19.4%); and mill residues (23%) [33].

Residues appear to provide the most fuel for US bioenergy sector, but since there is no set definition for 'residues,' it is not possible to know if this wood is truly the product of some other process. Conservative definitions for forest residues are found in Domke *et al*: the 'tip, portion of the stem above the merchantable bole, and all branches, and excluding foliage'

Figure 2. Trucks lined up waiting to deliver pellet feedstock to North Carolina plant owned by Enviva, the largest US pellet manufacturer. Much of the wood is tree trunks, not tops and limbs (Photo: Dogwood Alliance).

[20], and Laganière *et al*: 'all woody debris generated in harvest operations for traditional wood products (e.g. branches, tree tops, bark), excluding stumps and downed nonmerchantable trees' [12]. However, practices on the ground vary. For example, Dominion Energy Resources in Virginia, which re-fired three coal plants with wood and has a total bioenergy capacity of over 250 MW, wrote to the EPA that waste wood 'to us' means 'forest materials including residues (tree tops, non-merchantable sections of stem, branches, and bark), small trees and other low value materials' [38]. Some facilities clearly burn whole trees for fuel, like a new 70 MW plant in Berlin, New Hampshire that burns 113 tonnes of 'clean wood chips' per hour, including 'whole tree chips' [39] (Forisk lists this plant as burning 408 000 green tonnes of hardwood pulpwood and 408 000 green tonnes of residues per year [33]). The evidence for use of whole trees as fuel suggests that many facilities do not burn materials that meet conservative definitions of residues (i.e. branches, tree-tops, and bark left over from other harvesting).

Sources of wood utilized by the US pellet manufacturing industry

As of late 2016, annual production capacity at operating and under-construction wood pellet manufacturing facilities in the US was 13.2 Mt, requiring about 28.6 Mt of green wood as feedstock [33], though not all plants produced at capacity. Pellet companies emphasize use of residues, downplaying the use of roundwood as feedstock [40]. However, exported wood pellets must meet specifications including restrictions on bark content [41], thus there is a limit on the amount of low-diameter branches and tops that can be used. Accordingly, industry data indicate about 56% of pellet feedstock is supplied from pulpwood (41% from softwood, 14% from hardwood); 42% from mill residues, 1% from urban wood; and just 1% from logging residues [33]. Investigations of pellet feedstock at some large US mills have confirmed that a significant portion of feedstock is bolewood (figure 2). The feedstock supply from small pellet producers in the Northeastern US also appears to avoid residues; a study of nine pellet mills in Maine found only 2% came from tops and limbs, with the remainder classified as pulpwood or small diameter trees [42].

Similarly, company-supplied data on sources of wood pellets burned in the UK indicate that the majority of US pellets burned by the coal- and wood-fired Drax power station in 2015 was sourced from logs that 'formed part of the trunk of a tree which grew for at least ten years' from harvesting that was a 'mix of clearfell and thinning' [43]. While mill residues currently constitute a proportion of pellet feedstock in the US, they will not supply a meaningful amount for future capacity, because supplies are limited [44]. The dominance of pulpwood and the documented use of bolewood thus indicate that pellets often fail to meet the first condition for low carbon residues, that feedstocks genuinely be residues that if not collected would otherwise decompose or be burned without energy recovery.

Emissions from the US biomass industry

Emissions modeling examined the industrial and non-industrial bioenergy sectors separately. The model estimated cumulative direct CO_2 emissions from industrial facilities at 1135 Mt at year 10. However, because black liquor and other wastes provide a large proportion of industrial sector biomass, and the assumed alternate fate for these materials is combustion without energy recovery, cumulative net emissions are 224 Mt, for an NEI of 20% (figure 3(*a*)). Cumulative direct emissions for the smaller non-industrial sector are 208 Mt at year 10, but because the majority of fuel for this sector is wood and the weighted *k*-constant is lower, cumulative net emissions are 120 Mt and the NEI is 58% at year 10 (figure 3(*b*)). Both sectors show cumulative net emissions still increasing in the 40–50 year period, though less steeply than in the initial decades.

This analysis calculates emissions at the sector level as if all units initiated operation at the same time, while ideally, sector-level accounting would consider how long each facility has been operating. While inadequate data render this impractical, in general, the industrial sector has shrunk since the 1980s [45] and the present day NEI should be shifted toward the right (lower), as facilities are on average older. In contrast,

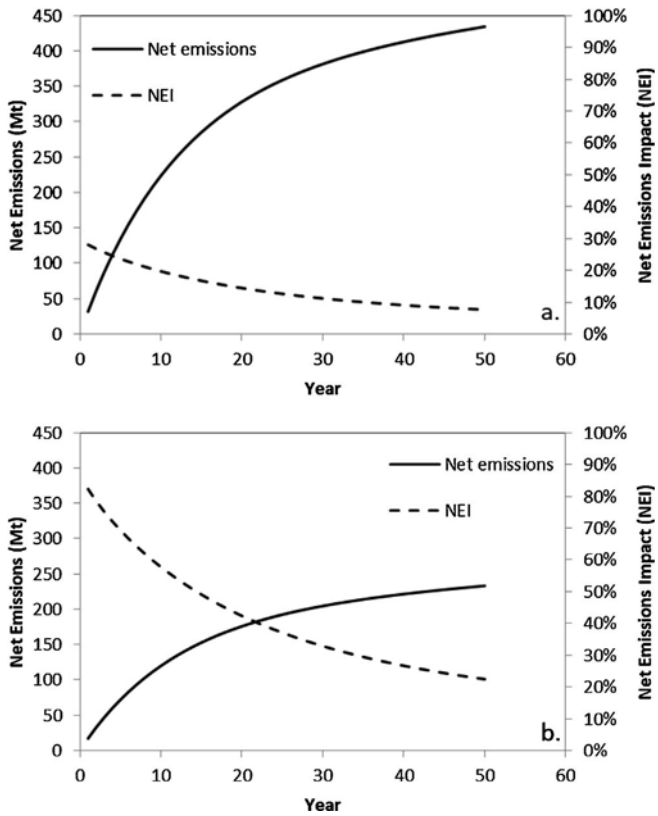

Figure 3. Cumulative net emissions and the NEI for the industrial (*a*) and non-industrial (*b*) bioenergy sectors over a 50 year timeframe, estimated using the average fuel mix for 2001–2016. High use of black liquor as fuel reduces the NEI for the industrial sector, while greater reliance on wood increases it for the non-industrial sector.

new construction of wood burning power plants and coal-to-wood conversions in the non-industrial sector since the early 2000s (figure 1) [28] means the average age of the sector is younger, shifting the NEI to the left (higher).

Refined emissions estimates for new wood-burning power plants

The industry-level analysis assumed an average *k*-constant for wood of 0.083, but plotting the NEI against the full range of *k*-constants (figure 4) demonstrates that the NEI for facilities burning forest residues exceeds 70% at year 10 for all decomposition constants lower than 0.07, and exceeds 40% at year 10 for the full range of decomposition constants for North American forests [46]. This conclusion is likely valid even if the alternative fate for wood is not being left in the forest to decompose, but disposal in a landfill. Conversion of carbon in landfilled wood to landfill gas (carbon dioxide and methane) is generally less than 3% after landfilling [47], thus even taking methane's global warming potential into account, the NEI from burning wood that would otherwise be landfilled is greater than 40% at year 10.

On a practical level, estimating stack emissions from a biomass power plant is easy, but estimating net emissions can be difficult, because the *k*-constant for wood can vary [48, 49]. One solution is to 'bracket' likely net emissions using a range of decomposition constants to estimate the NEI. Since burning a tonne of green wood emits about one tonne of CO_2, yearly direct emissions assuming a 4% HPT adjustment are about 1.04 tonnes per tonne of fuel, and cumulative direct emissions at year 10 are 10.4 tonnes. Taking a biomass facility located in the US southeast as an example, average decomposition constants for southeastern hardwoods (0.082) and softwoods (0.057) [46] translate to values of 67% and 75% on the ten year NEI curve; multiplying these NEI values by direct emissions gives cumulative net emissions of 6.97–7.80 tonnes of CO_2 at year 10 for each tonne of wood burned at such a facility. This approach to bracketing emissions could have policy applications. For instance, using the NEI to estimate net biogenic emissions could help integrate biomass power plants into carbon trading and carbon tax programs, as well as qualify bioenergy for renewable energy subsidies.

Emissions from wood pellets manufactured from residues

Emissions estimates for pellets calculated by the model certainly underestimate actual CO_2 impacts because tree boles constitute a large proportion of pellet feedstock, and it is unlikely that the true alternative fate for these materials is to be left onsite to decompose. However, calculating emissions as if claims about use of residues [40] were fully accurate can establish one type of 'best case' scenario for pellet emissions. Modeled

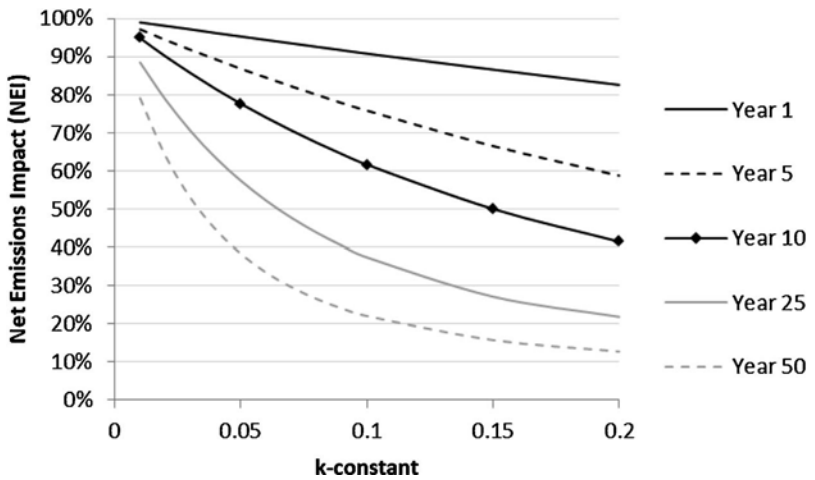

Figure 4. The NEI as a function of the *k*-constant at different points in time, assuming a 4% HPT adjustment. The NEI at year 10 is always greater than 40%, even when decomposition is assumed to be rapid.

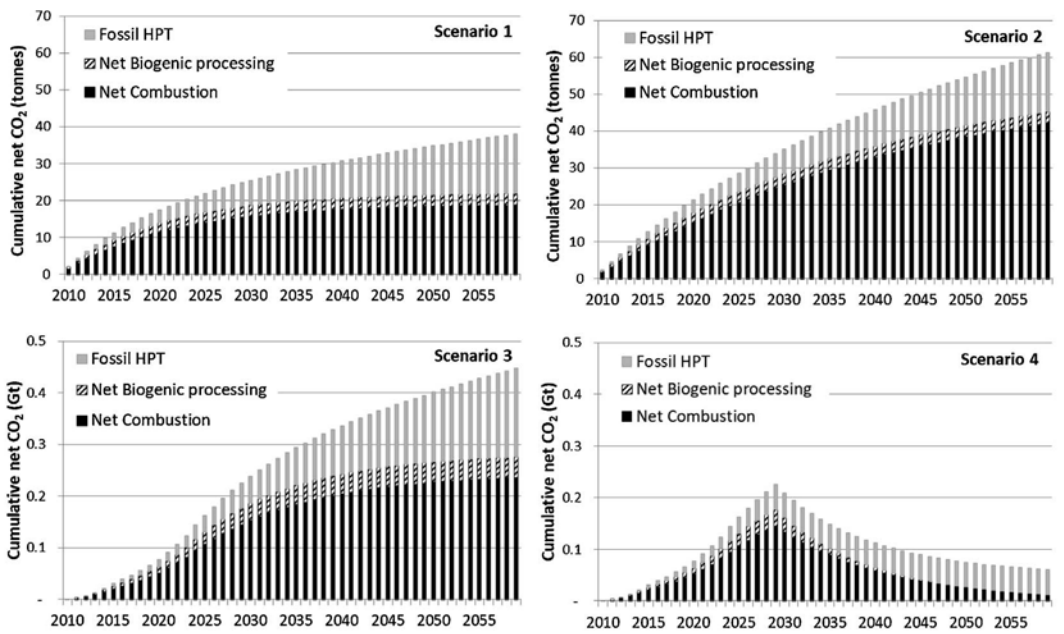

Figure 5. Cumulative net emissions for wood pellet scenarios 1–4 (details provided in table 2).

scenarios 1 and 2 estimate emissions from producing and burning one tonne of pellets per year from roundwood that is assumed to otherwise decompose onsite (figure 5 and table 2), illustrating the importance of the *k*-constant for net emissions. Even assuming very rapid decomposition ($k = 0.15$) as the counterfactual, the NEI for Scenario 1 is 55% at year 10. Scenario 2 employs a low *k*-constant (0.03) representing slower decomposition in a cool climate [11] such as Canada, and has an NEI of 79% at year 10; by year 25, cumulative net emissions are 40 tonnes CO_2 per tonne of pellet capacity, nearly double those of Scenario 1. Thus for both scenarios, simply counting cumulative direct emissions at year 10 would provide a closer representation of the emissions impact than characterizing pellets as 'carbon neutral,' as is current practice.

Scenarios 3 and 4 estimate net emissions from actual US pellet exports 2010–2016 [4, 5, 50, 51] followed by an increase to 12.8 Mt in 2024, commensurate with US exports meeting half of predicted short-term global demand for utility and industrial-use wood pellets by 2025 [5, 7]. These scenarios use a *k*-constant of 0.083, following a UK government-commissioned study on lifecycle impacts of wood pellets [11] that used values from a study of forest wood decay in North Carolina [52]. Accelerating use in the first part of scenario 3 elevates the NEI because decomposition emissions do not come into equilibrium with combustion emissions while pellet use keeps increasing. The NEI is 73% at year 10, 39% at year 40 and 34% at year 50. Scenario 4, where pellet use is terminated at year 20 (2030), has an NEI of 43% at year

25, because cumulative decomposition emissions of the counterfactual still have not caught up to combustion emissions from the early years of the scenario. This scenario shows a carbon benefit in terms of reduced emissions over time, but it requires actually stopping use of the fuel for this to occur.

Scenario 5 (shown in table 2 but not figure 5) uses actual data on global pellet use for 2010–2016, then projects growth to 66.4 Mt in 2025 [53], after which the model assumes demand is flat. It assumes not all pellets are manufactured in North America, thus HPT emissions are reduced by 15% to reflect shorter transport distances. With a pellet energy content of 17.5 MJ kg^{-1} [54], peak use of 66.4 Mt yr^{-1} represents 1.16 EJ annually, or just over 1% of the 100 EJ of new bioenergy projected to play a role in some mitigation models [1–3]. By year 40 (2050), cumulative net emissions are 1.99 Gt and are growing at 30 Mt per year.

The pellet scenarios demonstrate that fossil HPT emissions increase continuously with pellet use and represent a substantial 'non-vanishing' [25] fraction of net emissions. In reality, the model probably undercounts HPT emissions because it does not include releases of nitrous oxide emissions from fertilizer used on tree plantations [55] or methane emissions from wood chip piles [56] and finished pellets [36, 57]. Buildup of methane and other hazardous gases during transport and storage [58] is of concern to the wood pellet industry [59], and has the potential to add significantly to lifecycle greenhouse gas emissions [36]. The model also omits combustion emissions of black carbon, a significant climate forcer [60].

Most importantly, calculating net emissions from wood pellets as if feedstocks are derived from forest residues underestimates emissions because a large proportion of pellets are made from trees, not residues [41 61]. For instance, Stephenson and McCay (2014) [11] found net emissions were 10–12 times higher at year 40 when native hardwood trees are harvested for fuel, a practice that has been well documented in the US south [33, 41, 62, 63].

Conclusions

For bioenergy to offer genuine climate mitigation, it is essential to move beyond the assumption of instantaneous carbon neutrality. The NEI approach provides a simple means to estimate net bioenergy emissions over time, albeit one that tends to underestimate actual impacts. The model finds that for plants burning locally sourced wood residues, from 41% (extremely rapid decomposition) to 95% (very slow decomposition) of cumulative direct emissions should be counted as contributing to atmospheric carbon loading by year 10. Even by year 50 and beyond, the model shows that net emissions are a significant proportion of direct emissions for many fuels. Similarly, the model concludes that for wood pellets manufactured from residues in in the US and shipped overseas, even a rapid decomposition counterfactual produces an NEI of 55% at year 10, while a slow decomposition counterfactual produces an NEI of 79%. By year 40, net emissions still represent 25% to more than 50% of direct emissions. Scenarios that increase the amount of biomass burned each year, as is currently occurring in the EU, have even larger net emissions impacts.

Models like this have their critics. The IPCC warns that using a 'simple sum of the net CO_2 fluxes over time' to highlight the 'skewed time distribution between sources and sinks,' is probably insufficient to understand the climate implications of bioenergy, which instead requires models that include temperature effects and climate consequences [3]. Bioenergy advocates have seized on models that emphasize the importance of cumulative emissions for warming, pointing out that bioenergy can reduce carbon impacts over time compared to fossil fuels [23], though they say little about carbon impacts when bioenergy displaces zero-emissions technologies.

However, since the IPCC's call for more complex bioenergy modeling was published in 2014, the intensity of the climate crisis has deepened; in the US, legislation has been enacted that compels the EPA to treat bioenergy as carbon neutral [64]; and combustion of forest wood by the EU, UK and Asia is increasing each year, unmitigated by the carbon capture and storage that some climate models say is required [65]. Also while the climate modeling community ponders, governments are making practical decisions about renewable energy funding, as in the UK, where the government provided £809 m (about $1.2 b) [66 67] in subsidies to biomass electricity in 2015, the same year it announced it was terminating subsidies for offshore wind earlier than planned [68]. Since residues would eventually release carbon to the atmosphere whether through burning or decomposition, any putative reduction in CO_2 emissions actually depends on residues-fueled bioenergy displacing fossil fuels, but in the UK, it appears bioenergy may instead be displacing zero emissions technologies, while prolonging the life of coal plants that partially switch to subsidized wood burning.

There is no time like the present to reduce emissions. Given the anticipated role for bioenergy in climate mitigation, climate-related policies should be reformed immediately to account for bioenergy impacts. Using the NEI to weight biogenic CO_2 for inclusion in US and EU carbon trading programs and to qualify bioenergy for renewable energy subsidies would reduce emissions more effectively than continuing with the current assumption of zero emissions, though for wood pellets sourced from bolewood, counting direct emissions is a more protective and accurate approach.

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