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OPINION

Status and prospects for renewable energy using wood pellets from the southeastern United States

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Abstract

The ongoing debate about costs and benefits of wood-pellet based bioenergy production in the southeastern United States (SE USA) requires an understanding of the science and context influencing market decisions associated with its sustainability. Production of pellets has garnered much attention as US exports have grown from negligible amounts in the early 2000s to 4.6 million metric tonnes in 2015. Currently, 98% of these pellet exports are shipped to Europe to displace coal in power plants. We ask, 'How is the production of wood pellets in the SE USA affecting forest systems and the ecosystem services they provide?' To address this question, we review current forest conditions and the status of the wood products industry, how pellet production affects ecosystem services and biodiversity, and what methods are in place to monitor changes and protect vulnerable systems. Scientific studies provide evidence that wood pellets in the SE USA are a fraction of total forestry operations and can be produced while maintaining or improving forest ecosystem services. Ecosystem services are protected by the requirement to utilize loggers trained to apply scientifically based best management practices in planning and implementing harvest for the export market. Bioenergy markets supplement incomes to private rural landholders and provide an incentive for forest management practices that simultaneously benefit water quality and wildlife and reduce risk of fire and insect outbreaks. Bioenergy also increases the value of forest

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land to landowners, thereby decreasing likelihood of conversion to nonforest uses. Monitoring and evaluation are essential to verify that regulations and good practices are achieving goals and to enable timely responses if problems arise. Conducting rigorous research to understand how conditions change in response to management choices requires baseline data, monitoring, and appropriate reference scenarios. Long-term monitoring data on forest conditions should be publicly accessible and utilized to inform adaptive management.

Keywords: best management practices, biodiversity, bioenergy, carbon, ecosystem services, forests, pellets, southeastern United States, sustainability

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Introduction

Wood-pellet production in the southeastern United States (SE USA) has garnered much attention (Olesen *et al*., 2016; Cornwall, 2017) as exports have grown from negligible amounts in the early 2000s to 4.6 million metric tonnes in 2015 (US International Trade Commission, 2016). In 2015, 98% of these pellets were shipped from the SE USA to the European Union (EU) for bioenergy (US International Trade Commission, 2016). As EU pellet demand has grown, debate has increased about potential effects on SE US forests. Environmental organizations and others have expressed concerns about potential impacts on old-growth and bottomland forests (forested wetlands that experience occasional flooding in the SE USA), net greenhouse gas (GHG) emissions, and biodiversity (Olesen *et al*., 2016; Cornwall, 2017). Yet the US Department of Agriculture (USDA) Forest Service identifies the greatest risks to SE US forests as urban expansion and land development, lack of market demand for wood products, and increases in invasive species, fires, and other disturbances related to climate change (Wear *et al*., 2013), although these risks are overlooked in some studies (e.g., Cornwall, 2017).

Evidence-based analysis is essential to address concerns and inform decision making. Evaluating effects requires an understanding of how wood-pellet demand interacts with other forest product markets and the extent to which pellet production induces synergies, tradeoffs, or other costs and benefits that can be differentiated from the effects of ongoing forestry practices in the absence of pellet markets. Our aim is to present an objective review of key issues, constraints, and opportunities associated with the wood-based pellets industry, based on documented effects of wood-pellet production on forest conditions in the SE USA.

Demand and production of wood pellets

The recent growth in global pellet demand has been driven largely by EU renewable energy targets to cut GHG emissions in 2020 by 20% from 1990 levels. European policies promoting bioenergy are partially predicated on analysis showing that increased use of bioenergy can contribute to both energy and climate objectives (Dale *et al*., 2015a; Berndes *et al*., 2016; European Union, 2016). The EU and individual member-state bioenergy policies include a mix of tax exemptions, mandatory targets, electric power feed-in tariffs, direct subsidies, and solid biomass sustainability policies that stimulate market growth of imported wood pellets (Abt *et al*., 2014; Alberici *et al*., 2014).

Wood-pellet production in the SE USA has emerged in response to several factors. The decline of pulp and paper operations has resulted in stranded wood supplies. Making pellets maintains employment in regions where the forest products industry has been a key economic driver. In addition, by-products of sawmill operations and forest management (e.g., from tree thinning to maximize timber yield, unmerchantable stems or from harvest residues such as branches and tops) provide pellet feedstock (Morrison & Golden, 2016). Furthermore, access to EU markets for pellets from SE USA is facilitated by carbon- and cost-efficient maritime shipping (Dwivedi *et al*., 2014), high-volume direct shipping lanes, and proximity of ports to productive timberlands with established forest product supply chains. Although pellet exports rose sharply after 2007, biomass for pellets comprised only 2% of total harvest removals in the SE USA in 2014 (Fig. 1), with traditional pulpwood and sawtimber representing the other 98% (Stewart, 2015). International trade data show that pellets comprised <1% of total US forestry products by weight and <0.5% of total US forest products export value during 2014 (FAOSTAT-Forestry Database, 2016, based on conversion factors in Lamers (2013) and UNECE (2009)).

Forest history sets the stage

The production of wood-based pellets should be viewed in light of the dramatic changes that the SE US landscape has undergone since large-scale settlement began in the 18th century. Two centuries of development, row crop cultivation and almost complete forest conversion resulted in high soil erosion rates. As crop production became less competitive in the eastern USA, it moved to

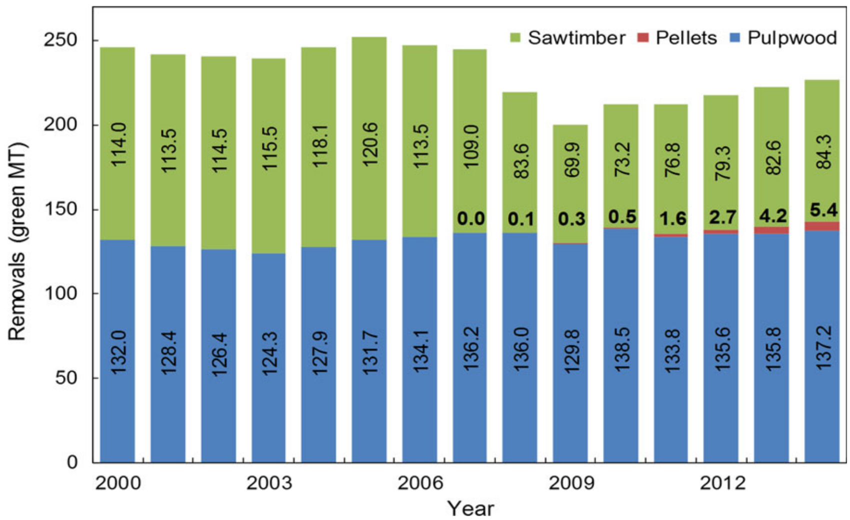

Fig. 1 Annual forest harvest removals in the SE USA shown in green million metric tonnes (MT) based on Forest2Market data reported for the Atlantic and Gulf regions (Stewart, 2015). In this figure, 2 tonnes of green wood are assumed to produce 1 tonne of dry pellets.

regions better suited to intensive agriculture and afforestation ensued (Davis, 1996). Although only 12% of global forest area is privately owned (White & Martin, 2002), 87% of SE US timberland is privately owned and about 60% is family owned (Oswalt *et al.*, 2014). Whereas institutional owners (e.g., private forest products corporations and investment firms) respond primarily to market signals, management decisions of family forest owners are motivated by diverse interests including asset preservation, profit generation, aesthetics, wildlife and recreational opportunities, and inheritance for heirs (Butler *et al.*, 2017). Harvesting decisions by family forest owners are frequently triggered by life events, such as the need to raise money for medical treatment, education, or retirement (Butler *et al.*, 2017), or by a change in ownership.

Concerns

Effects on old-growth forests

The potential for pellet-wood production to affect old-growth forests has been raised as an issue by some conservationists. However, the legacy of land clearing, logging, and agriculture has left only isolated pockets of old-growth forest in the SE USA (Davis, 1996). Remnant old-growth forests (as defined by advanced tree age, minimal human disturbance, and mature successional stage of the forest) are valued for their ecological characteristics and are almost exclusively found in protected areas where logging is prohibited (Davis, 1996). US federal policy instruments safeguarding all forests include protection of rare species under the Endangered Species Act, Safe Harbor Agreements and Habitat Conservation Plans (on private lands), and protection of ecosystem services under the Clean Water Act and Clean Air Act. State agencies, land trusts, nongovernmental organization, and citizen alliances safeguard state and private forests (Davis, 1996). Depending on the forest type and condition, that protection may involve active management. For example, fire-dependent, native longleaf pine (*Pinus palustris*) stands that once blanketed large areas of the SE USA have been reduced to 3% of their original area as a result of settlement and fire suppression (Varner *et al.*, 2005). Removing hardwood trees and management of understory vegetation via controlled burns and other practices is key for restoring the longleaf pine ecosystem across its former range and maintaining open canopy conditions in other pine forest types (Varner *et al.*, 2005; Greene *et al.*, 2016), and bioenergy can offer a market for that material.

Effects on bottomland forests

The effect of wood-pellet production on bottomland forests is also a concern. Over the past two centuries, nearly all bottomland forests were converted to other land uses (as much as 80% in some regions (De Steven *et al.*, 2015)) or have been managed for wood products. Important challenges to bottomland forest ecosystems include (i) conversion to urban uses (Wear *et al.*, 2013); (ii) anthropogenic alterations in flooding patterns (Cooper *et al.*, 2009) including those associated with dikes, dredging, oil and gas extraction, and salt water intrusion; and (iii) high populations of white-tailed deer (*Odocoileus virginianus*) that promote expansion of

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invasive plant species and alter tree species composition (Cogger *et al.*, 2014).

A variety of conservation programs have promoted restoration of bottomland forests previously converted to other land uses. In the 13 states that comprise the Forest Service southern forest region, nearly four thousand tracts covering more than 526 000 hectares (ha) were enrolled in the Wetlands Reserve Program from 2009–2015 to protect, restore, and enhance wetlands and bottomland forests on private farmland (King *et al.*, 2006; NRCS, 2016). Since the 1990s, over 275 000 ha of bottomland forest have been restored in the lower Mississippi River valley alone, mostly on private farmland (Berkowitz, 2013).

Conservation easements often involve management, including harvest. Forest management practices in wetlands are exempt from the Clean Water Act permitting requirements, although other regulations to protect water and biodiversity are applicable. Forest management activities cannot convert wetlands to another land use and must protect threatened and endangered species. Federal and state policies and programs such as the Endangered Species Act, state water quality laws, and forestry best management practices (BMPs) protect rare species, habitats and water quality. Zoning and taxation may further restrict allowable activities, and some pellet producers have a formal policy not to source biomass from rare forest ecosystems such as cypress and tupelo stands in wetlands (Drax Biomass Inc., 2016) and sensitive bottomland forests (Enviva Forest Conservation Funds, 2016).

While timber harvesting cycles in bottomland forests have short-term (e.g., annual to decadal) effects including declines of standing carbon stocks and alteration of habitat for forest species, managing these lands for forestry is ecologically preferable to their transformation to nonforest alternatives. As with all land-use activities, effects on biodiversity and ecosystem services of harvesting bottomland forests for bioenergy are highly variable and context specific and can have differential effects across the landscape and over time (Costanza *et al.*, 2016; Tarr *et al.*, 2016). Negative impacts of bioenergy harvests can be avoided or reduced by identifying priority areas for conservation and adopting management plans tailored to best achieve multiple goals in production forests (Joly *et al.*, 2015).

Effects on climate change

Climate change impacts are another concern in the production of wood-based pellets. The Intergovernmental Panel on Climate Change (IPCC, 2014) distinguishes between the slow domain of the carbon cycle, where turnover times exceed 10 000 years, and the fast domain (the atmosphere, ocean, vegetation, and soil), where vegetation and soil carbon have turnover times of 1–100 and 10–500 years, respectively. Fossil-fuel use transfers carbon from the slow domain to the fast domain, while bioenergy systems operate within the fast domain (Ciais *et al.*, 2013). Using wood for energy displaces fossil fuels (mostly coal) and can contribute to the phasing out of technologies and infrastructures that cause fossil carbon emissions, which is necessary for keeping fossil sources secured underground (Ter-Mikaelian *et al.*, 2015; Berndes *et al.*, 2016; Galik & Abt, 2016).

Fossil-fuel inputs to wood-pellet supply chains typically correspond to a small fraction of the energy content in the produced pellets, and fossil carbon emissions are small compared to the biogenic carbon flows associated with forest operations, transport, and pellet use (Eriksson *et al.*, 2007; Lindholm *et al.*, 2011; Gustavsson *et al.*, 2011; Lamers & Junginger, 2013; Hansson *et al.*, 2015). Thus, concerns about climate effects of wood-pellet production are mainly related to how the forest carbon cycle is affected by management changes that may result from wood-pellet production systems.

As concluded by the IPCC (2014), it is the cumulative emissions of CO_2 that largely determine global warming by the late 21st century and beyond. Woody bioenergy affects cumulative emissions through two primary mechanisms: change in biospheric carbon stocks and displacement of fossil fuel. If the goal is to stabilize global warming within a 2-degree target, for example, then critical questions are how bioenergy markets influence net changes in total biospheric carbon stocks and net changes in fossil-fuel use. The latter depends largely on how bioenergy policies influence investments in fossil-fuel-based technologies and infrastructure, which has implications for future GHG emissions. A recent analysis for Canada, in which substitution values for wood products were considered across their life cycle, found that the greatest avoided emissions occurred when bioenergy was substituted for energy obtained from high-emission fossil fuel such as coal (Smyth *et al.*, 2016).

There is no question that the use of wood from managed forests to displace fossil-based energy reduces net GHG emissions over multiple cycles of forest harvest and re-growth (Ter-Mikaelian *et al.*, 2015; Galik & Abt, 2016). It is rather the timing of net GHG savings that is currently debated, and the science literature provides different views, depending on policy objectives and context, which have a major influence on the formulation of research questions, the scale and system delineation, and other critical parameters that influence the results and conclusions (Helin *et al.*, 2013; Miner *et al.*, 2014; Dale *et al.*, 2015a; Berndes *et al.*, 2016; Cintas *et al.*, 2017).

Life cycle assessment studies concerning displacement of fossil-fuel-based EU electricity generation from SE US pellets show that GHG savings occur over varying time scales (Dwivedi *et al.*, 2014; Giuntoli *et al.*, 2015; Wang *et al.*, 2015; Fingerman *et al.*, 2016; Hanssen *et al.*, 2017). When pellets are produced from precommercial thinnings, harvest residues and mill residues, the previously sequestered carbon is returned to the atmosphere via pellet combustion in heat and power plants. This process may occur faster or slower than when the carbon is returned via decomposition or burning on site. If the pellet use returns the carbon to the atmosphere faster than decomposition or burning, short-term increases in net GHG emissions occur unless the GHG emissions savings from displacing fossil fuels outweigh the biogenic carbon emissions. The choice of spatial and temporal boundaries for analysis and the choice of reference case or counterfactual scenario affect the result and may mean that different studies come to different conclusions about the same bioenergy system (Marland *et al.*, 2013; Buchholz *et al.*, 2014; Wang *et al.*, 2015). The outcome, in addition, depends on the broader consequences of the bioenergy market itself on forest management, disturbance regimes, and forest expansion, which may or may not be considered in studies (Cowie *et al.*, 2013; Berndes *et al.*, 2016)

Overall forest stocks in the SE USA have increased for the last 50 years and are projected to continue increasing if conversion to nonforest uses is low (Wear *et al.*, 2013), while also supporting significant removals for sawtimber, pulpwood and wood-pellet production (Oswalt *et al.*, 2014; Woodall *et al.*, 2015; USDA Forest Service, 2016). On intensively managed, corporate-owned timberland, carbon stocks are essentially stable (Heath *et al.*, 2010). The presence of a bioenergy market increases the economic attractiveness of forestry, which, in turn, supports maintenance and expansion of SE forest lands and their carbon sink capacity (Miner *et al.*, 2014; Zhang *et al.*, 2015), where that capacity is defined by the ability to store more above- and below-ground carbon both now and in the future. The USDA projects declines in the SE US forest area of up to 8.5 million ha or 10% between 2010 and 2060, largely driven by population growth, income-driven urbanization and a greater projected economic attractiveness of agricultural products as compared to timber products (Wear *et al.*, 2013). Private forest landowners will need incentives, financial or otherwise, to retain forested land as forest. Loss of forested land area is one of prime causes of decline in forest carbon stocks (Körner, 2017).

In the face of uncertain future demand for lumber and other forest products (Wear *et al.*, 2013), an increase in the price of wood pellets may motivate land owners to implement shorter rotations, higher density planting, or more frequent thinning (Olesen *et al.*, 2016), which could affect carbon stocks. That being said, there is no evidence to date of a change in stocking density trends based on analysis of the US Forest Service Forest Inventory and Analysis (FIA) data for counties in the SE USA with high pellet production (Dale *et al.*, in press). Furthermore, prices for bioenergy feedstocks are unlikely to increase enough to drive wholesale shifts in forest management to favor pellet production because low-cost biomass (e.g., agricultural, logging and wood-processing residues) is plentiful across the globe.

Addressing concerns about environmental effects of bioenergy

Reliable demand for wood-based bioenergy helps address the concerns mentioned above, for it improves the business proposition to retain land in forest (Galik & Abt, 2016) and to apply practices that improve forest conditions (Anderson & Mitchell, 2016). While high-value sawtimber and pulp markets are expected to continue driving major forest management decisions, a market for low-value stems, residues and roundwood (where demand is otherwise weak) helps support better forest management, for example, by reducing the practice of slash burning to dispose of unmerchantable biomass. Furthermore, markets for products made from low-value wood provide extra income (Malmsheimer & Fernholz, 2015) that can be used for management practices such as thinning that decrease risks of insect outbreaks, disease and destructive wildfire (Coppoletta *et al.*, 2016); increase site productivity and consequent carbon uptake rates (Fox *et al.*, 2007); and address non-timber objectives such as recreation and habitat for wildlife (Evans *et al.*, 2013). Benefits of controlling disease, pests and fires on private forests extend to neighboring forests, public lands and reserves (Malmsheimer *et al.*, 2011; Dale *et al.*, 2015a).

In addition, multiple environmental benefits can be achieved via the use of wood for bioenergy. Wood pellets provide a renewable alternative to the primary anthropogenic cause of environmental effects associated with climate change: fossil-fuel use (Cowie *et al.*, 2013; Berndes *et al.*, 2016). Without bioenergy markets, woody material cut for land clearing or leftover from thinning and harvest slash is often burned on site or left to decay in piles and may, thereby, increase the potential wildfire fuel load (Fig. 2). Furthermore, mid-rotation thinning increases both forest water yield and land-owner profits (Susaeta *et al.*, 2016), and those thinnings could provide biomass for bioenergy. Hence, forest management that delivers multiple benefits for the region can be a way to support both sustained employment and diverse

Fig. 2 In east Tennessee, much wood is left on the ground after a clear-cut where it decomposes and gradually releases carbon to the atmosphere (a). After a forest clearing in northern Florida, whole trees and residues are piled (b) and then pushed into a pit to be burned (c) resulting in immediate release of carbon into the atmosphere. Both practices are common across the SE USA. Note that the person on the right in photograph b shows the size of that pile. Photograph credits: Keith Kline.

ecosystem services (Meyer *et al.*, 2015). When residues are removed for bioenergy, economic and operational limitations, as well as BMPs, ensure that adequate woody debris remains on site to protect soil and water quality (Neary & Koestner, 2012; Evans *et al.*, 2013; Fritts *et al.*, 2014; Cristan *et al.*, 2016).

Best management practices define practices to minimize soil disturbance and water quality impacts from bioenergy operations, including timber harvest and residue removal (Ice *et al.*, 2010). Neary & Koestner (2012) report that forest bioenergy production systems can be compatible with maintaining high quality water supplies in forest catchments. In their review of 30 research studies of BMPs in the SE USA, Cristan *et al.* (2016) found that forestry BMPs efficiently protect water yield and quality (e.g., decrease suspended sediment flux and concentrations of nitrate and other nutrients). Furthermore, a detailed study of Coastal Plain loblolly pine (*Pinus taeda*) plantations (where Biomass Harvesting Guidelines recommend retaining a portion of woody biomass on the forest floor following harvest) found that removal of residues from clear-cut sites for bioenergy feedstock does not impact herpetofauna, breeding bird, or winter bird populations (Fritts *et al.*, 2016; Grodsky *et al.*, 2016a,b). An integrated approach that bundles ecosystem services and financial incentives offers a means to address the diverse values of forests via proactive forest management (Deal *et al.*, 2012). BMPs, in combination with a market for wood-based pellets, provide such an approach.

Forest management can cause changes in the partitioning of precipitation between runoff, drainage, evaporation and plant transpiration (Berndes, 2002; Jackson *et al.*, 2005; Bonsch *et al.*, 2017). Measures to enhance biomass production, such as expanding forest area, shifting to shorter rotations, or increasing stocking rates (more trees per area) or forest area, can lead to increased evapotranspiration and possibly greater risk of water stress in areas of water scarcity. Measures to enhance biomass production for energy can also be beneficial and reduce water risk, for example, the probability of experiencing a deleterious water-related event. For example, in humid areas and on steep slopes, the establishment of tree cover can decrease erosion and flood risk by reducing runoff and increasing infiltration and retention of rain water in the soil. Matching bioenergy feedstocks and management practices to local conditions and constraints is essential and possible (King *et al.*, 2013). For example, Susaeta *et al.* (2016) report that privately owned forests could become an important potential source of additional water supply in SE USA under a forest-water-yield-payment system.

To ensure that wood pellets used in industrial, large-scale energy production contribute to mitigating climate change without unacceptable impacts on biodiversity and ecosystem services, the major wood-pellet-importing EU nations require that forest operations be certified to internationally accepted sustainability standards. Institutional forests commonly meet this requirement, but small SE US family forest owners often lack the resources or incentives to engage in such processes (Morris, 2014). However, most commercial timber harvests in the SE USA are performed following state-defined BMPs (Wear & Greis, 2013), with implementation rates exceeding 90% (National Association of State Foresters, 2015). Mills that export wood pellets require feedstock to originate from sites where the logging is supervised by professionals trained in wildlife habitat conservation, water quality protection, and other BMPs (National Association of State Foresters, 2015). Logger training is a component of the Sustainable Forestry Initiative's certified Fiber Sourcing Standard, which sets expectations for responsible procurement of all fiber and is audited by an independent third party. Loggers who received training are more likely to implement BMPs during harvesting operations on nonindustrial private forests (Davis & Clatterbuck, 2003).

The value of systematic monitoring and transparency

Publicly available science-based information can bolster public trust and confidence in the effects of forest management changes (e.g., FIA, 2012; Norman *et al.*, 2013; National Association of State Foresters, 2015; Butler *et al.*, 2017) by providing evidence to determine whether bioenergy from SE US wood pellets achieves desired goals. State and federal regulations and BMPs, forest and fiber-sourcing certification programs, nonprofit conservation organizations, land trusts, and logger training programs provide a network of support and accountability for protection of both public and private SE US forest lands. The effectiveness of these safeguards is documented via ongoing collection and analysis of consistent data on actual forest conditions (FIA (Forest Inventory and Analysis), 2012), as required in the USA by the Resources Planning Act Assessment (Butler *et al.*, 2017). The application and effectiveness of BMPs undergo systematic reviews that document costs and benefits (Cristan *et al.*, 2016) as well as provide feedback to guide their continual improvement, which is a core principle of sustainable forest management (Lattimore *et al.*, 2009; Dale *et al.*, 2015b; ASTM 2016). Furthermore, when considering effects of BMPs at a watershed scale, weight-of-evidence approaches that include monitoring of multiple response parameters may be the most useful approach (Ice, 2011).

An indirect benefit of pellet demand is that EU renewable energy and climate policies are driving intensive reviews of current practices that could lead to improvements in forest management across the SE USA. To maximize this potential and mitigate risks, the costs, benefits, socioeconomic implications, and opportunities of wood-based bioenergy should be scientifically quantified on a regional basis to inform decisions regarding tradeoffs among energy options, forest use, and multiple environmental objectives. Continued monitoring of the effects of forest harvest and management and implementation of sustainable management practices are necessary to instill confidence that priority forest ecosystems are conserved, water quality is protected, and BMPs are followed. Furthermore, the net effects of bioenergy systems need to be monitored to verify that they are helping to achieve both near-term emission reduction targets and long-term temperature targets.

Conclusion

Forests produce a range of products: sawlogs, pulp logs, low-value logs, and poles as well as residues. How the forest is managed affects the proportion of each product available, revenues, and environmental effects. Renewable bioenergy should ideally improve the delivery of social, economic and environmental benefits from forestry. Bioenergy markets can assist landowners and society to achieve desired economic, social, and environmental outcomes by supplementing incomes to private landholders and thereby enabling management required to improve forest conditions and protect ecosystem services.

The balance of evidence, some of which is reviewed here, suggests that current levels of wood-pellet production in the SE USA have had a benign effect on forest ecosystem services. Future production has the potential for positive effects when it builds landowner commitment to retain land in forest cover and when wood-pellet production becomes more efficiently integrated into proactive forest management plans. Regulatory and voluntary provisions exist to protect forests. Nonetheless, systematic monitoring and evaluation of managed forests are essential to ensure that intended outcomes are achieved. Knowledge gained from monitoring and rigorous scientific research should be used to inform continual improvement of forest management and should be reflected in decision making in both the USA and the EU.

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