

ORIGINAL RESEARCH

Continued obstacles to wood-based biomass production in the southeastern United States

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Abstract

International demand for wood-based biomass for bioenergy production is growing, and private forestlands in the southeastern United States have the potential to supply that demand. The southeastern United States (Southeast) is the world's largest exporter of wood pellets for bioenergy, primarily to the United Kingdom (UK) and the European Union (EU). However, wood-based biomass production accounts for only a small share of total wood removals from private forestlands in the Southeast. There is sufficient wood-based biomass in the Southeast to support greater production of wood pellets for domestic and international markets without redirecting timber from sawtimber and pulpwood production. In 2018–19, we conducted 39 semi-structured interviews with private forest landowners, foresters, loggers, and biomass production facility managers in Alabama, Florida, and Georgia to obtain their views on wood-based biomass production in the Southeast. Although landowners were interested in supplying wood for biomass as a byproduct of timber harvesting, they seldom participated in wood-based biomass production because of limited and unreliable access to biomass markets. Loggers and production facility managers had not invested in biomass production because they remain skeptical about the financial viability of wood-based biomass. Continued obstacles to biomass production include: price competition with fossil fuels and conventional wood products; inconsistent domestic government support for biomass production; concerns about meeting the sustainability requirements to export wood-based biomass to the UK and EU; and the high costs associated with harvesting low-grade wood for biomass. The barriers to biomass expansion in the southeastern United States remain primarily economic and political rather than biophysical.

KEYWORDS

non-industrial private forest landowners, qualitative analysis, real estate investment trusts, semi-structured interviews, timber investment management organizations

1 | INTRODUCTION

Bioenergy is a key focus of international efforts to transition to renewable energy, improve energy security, reduce coal

consumption, and limit climate change (Hodges et al., 2019a; Kittler et al., 2020). The global biomass power market was valued at USD 49.8 billion in 2019 and is expected to grow at a compound annual growth rate of 9.2% to USD 98.0 billion

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in 2027 (Grand View Research, 2020). The European Union's (EU) Renewable Energy Directive II mandates that by 2030 32% of the energy consumed within the EU must be renewable (European Commission, 2019; The European Parliament and the Council of the European Union, 2018). The United Kingdom (UK), which is the world's largest importer of wood pellets for bioenergy has the intention of doubling their bioeconomy by 2030 through international partnerships (U.K. Department for Business, Energy, & Industrial Strategy, 2018). The United States has also implemented multiple policies to promote biomass for bioenergy production nationally, including: the Renewable Fuels Standard provision of the 2007 Energy Independence and Security Act; the Biomass Crop Assistance Program (BCAP), which provided financial assistance for producing biomass feedstocks on agricultural and non-industrial private forest (NIPF) lands (United States Department of Agriculture, 2016); and the *Consolidated Appropriations Act* (H.R. 1625), which established national directives to encourage private investment throughout the forest biomass supply chain (United States Environmental Protection Agency, United States Department of Agriculture, & United States Department of Energy, 2018). Although wood-based biomass accounted less than 1% of the United States' net electricity generation in 2020 (U.S. Energy Information Administration, 2021a), forest bioenergy supply chains in the United States are growing in response to increased international demand for wood-based biomass (Kittler et al., 2020). The southeastern United States (Southeast), which contains highly productive pine plantations and forests, plays a key role in supplying wood-based biomass (notably, wood fibers compressed into pellets) to the UK, Europe, and emerging bioenergy markets in Asia (Aguilar et al., 2020; Kittler et al., 2020; TimberMart-South, 2019; U.S. International Trade Commission, 2016).

In 2018, the UK and EU consumed approximately 23 million metric tons of wood pellets, 27% of which (6.1 million tons) was supplied by the United States (Kittler et al., 2020). Moreover, suppliers in the Southeast have contracted to provide Japan with 1.5 million tons of wood pellets (Kittler et al., 2020). International demand for wood pellets triggered construction of new wood pellet mills in the Southeast with an associated increase in pellet manufacturing capacity from ≤ 0.3 million tons prior to 2009 to an estimated 9.0 million tons currently (Aguilar et al., 2020; see also Dale et al., 2017; concurrently, the number and capacity of wood pellet mills in the rest of the eastern United States expanded to meet domestic demand for wood-based biomass, although the capacity of these mills is far lower; Aguilar et al., 2020). Wood pellet exports grew by 180% from 2.06 to 5.7 million tons between 2012 and 2017 (Brandeis & Abt, 2019; U. S. International Trade Commission, 2018).

Nonetheless, wood pellets are still a small share (3%) of the total volume of wood products exported from the

Southeast (Kittler et al., 2020), and the pellet industry accounts for <1% of US forest products by weight (Dale et al., 2017). In 2014, the volume of harvested biomass used for wood pellets constituted approximately 2% of total timber harvest removals in the Southeast (Hodges et al., 2019a). In contrast, pulpwood and sawtimber account for approximately 80% of timber harvest removals in the Southeast (United States Department of Agriculture, 2021). Feasibility analysis suggests that an additional 182 wood pellet plants could be supported in the Southeast without changing current patterns of pulpwood use (Henderson et al., 2017), that is, available wood-based biomass is not being directed to wood pellet production. This raises the question why wood-based biomass production accounts for only a small share of total wood removals from private forestlands in the Southeast.

Wood pellet mills that supply wood-based biomass to international markets source biomass from NIPF and industrial forestlands in the Southeast (Aguilar et al., 2020; Kittler et al., 2020). Specifically, mills source primary fiber in the form of timber harvest residuals (tree tops, limbs, bark, foliage, and other nonmerchantable materials that are generated during roundwood timber harvests), secondary residuals (sawdust, wood shavings, chips, and other by-products of sawmills, pulp and paper mills, and wood manufacturers), and occasionally tertiary residuals (post-consumer wood waste) to generate wood pellets (Kittler et al., 2020; see also Aguilar et al., 2020). Wood pellets are produced from residual wood-based biomass materials that are generated by larger, higher-value industries such as lumber and paper (Hodges et al., 2019a). Non-sawtimber roundwood (pulpwood size logs, small-diameter trees from forest thinning, low-priced chip-n-saw logs, defect logs) may also be used to generate wood pellets (Hodges et al., 2019a; Kittler et al., 2020).

Larger pellet mills (>300,000 metric tons per year production capacity) mostly use primary fiber that is sourced from private industrial and non-industrial forests in the Southeast to generate wood pellets, although they do not maintain long-term supply contracts with private landowners (Kittler et al., 2020). Private landowners play a key role in supplying wood-based biomass because they own the majority of the 267 million acres of forestland in the Southeast (Oswalt et al., 2014). NIPF landowners own 56% of all forestlands in the Southeast (Zhang et al., 2012). Corporate landowners, such as timberland investment management organizations (TIMOs) and real estate investment trusts (REITs), own 30% of all forestlands in the Southeast (Zhang et al., 2012). Pellet mills also source a substantial share of primary fiber from wood dealers (foresters and loggers) who network with landowners in the Southeast (Kittler et al., 2020). Primary fiber is typically sourced from private lands that are within a 50- to 75-mile haul distance from pellet mills (Kittler et al., 2020). On average, most of the wood pellets produced in the

United States are 80% primary fiber and 20% roundwood (Hodges et al., 2019a) or secondary residuals (Brandeis & Abt, 2019), although Kittler et al. (2020) found that larger pellet mills were transitioning to greater use of secondary residuals because these residuals can be purchased at lower cost.

Recent research has highlighted several challenges inherent in the production of wood pellets in the Southeast. Regulatory requirements by the UK and EU member countries (e.g., criteria by the Netherlands per the Stimulation of Sustainable Energy Production, SDE+) to ensure sustainability of wood-based biomass production have impacted the biomass sourcing strategies and supply chains for wood pellet plants (Dale et al., 2016; Kittler et al., 2020). Wood pellet mills are expected to demonstrate that they comply with various sustainability policies, for example: the Sustainable Forestry Initiative (SFI) forest management (SFI FM), chain of custody (SFI COC), or fiber sourcing (SFI FS) certifications; the American Tree Farm System (ATFS); the Program on Endorsement of Forest Certification Controlled Sourcing (PEFC CS); the Forest Stewardship Council (FSC) forest management certification (FSC FM), chain of custody (FSC COC), and Controlled Wood (FSC CW) certifications; or the Sustainable Biomass Program (SBP; Dale et al., 2016; Kittler et al., 2020). Mills and landowners are also expected to comply with state and federal policies that govern environmental quality. To meet these standards, mills audit feedstock suppliers to ensure compliance with chain of custody requirements, conduct spatial risk assessments, and offer to certify the forest management plans of landowners who supply sawmills (who in turn supply mill residuals to the pellet mill; Kittler et al., 2020). Nonetheless, Kittler et al. (2020) found that only a small volume of wood fiber can be traced to forests certified under a forest management certification standard unless wood pellet mills are closely linked to another forest products facility such as a sawmill or an industrial landowner with the SFI certifications. In addition to sustainability certification issues, prior research suggests that NIPF landowners have not entered the bioenergy market because they lack knowledge about what woody materials can be sold as biomass, how biomass production can complement their other land management practices, and the existence of markets for wood-based biomass (Hodges et al., 2019a; Joshi & Mehmood, 2011a, 2011b; Joshi et al., 2013). NIPF landowners have also demonstrated concerns about the viability of bioenergy markets in the long run (Hodges et al., 2019a).

Although prior research provides important insights into the logistical complexities of wood pellet production, more information is needed to understand why landowners (in particular, corporate landowners, REITs and TIMOs), loggers and foresters may have reservations about participating in wood-based biomass production. Accordingly, we conducted a series of interviews with key informants (landowners,

loggers, foresters, and pellet mills) to explore why wood-based biomass production accounts for only a small share of total wood removals from private forestlands in the Southeast. To help answer this question, we elicited different stakeholders' opinions about opportunities for and barriers to wood-based biomass production in the Southeast.

2 | METHODS

2.1 | Study area

Our research focused on private timberlands in the key wood-based bioenergy states of Alabama, Georgia, and Florida (Gottlieb et al., 2017; United States Department of Agriculture, 2010). The Southern Coastal Plains and Southeastern Plains ecoregions include high concentrations of private pine plantations (Zhang & Polyakov, 2010) that are used to produce wood products, including saw logs, veneer logs, pulpwood, composite panels, and wood pellets (Costanza et al., 2017; U.S. Department of Energy, 2016; Wall et al., 2017a, 2017b, 2017c). Average annual pulpwood growth totals 7.40 million dry tons in Alabama (of which 3.17 million dry tons are removed annually during harvest), 4.09 million dry tons in Florida (1.93 million dry tons removed), and 7.66 million dry tons in Georgia (4.15 million dry tons removed; Henderson et al., 2017). Alabama, Florida and Georgia contain 118, 56 and 190 plants that process roundwood, respectively (Wall et al., 2017a, 2017b, 2017c). In 2015, industrial timber product output from all wood products was 1.10 billion cubic feet in Alabama, 523.2 million cubic feet in Florida, and 1.34 billion cubic feet in Georgia (Wall et al., 2017a, 2017b, 2017c). Wood-based biomass for bioenergy is generally one of the lowest value wood products, for which landowners receive \$2 per ton or less. By contrast, in 2019, pine pulpwood sold for an average stumpage price of \$11.01 per ton and hardwood pulpwood sold for an average stumpage price of \$10.77 per ton across Alabama, Florida, and Georgia (TimberMart-South, 2020).

2.2 | Data collection

From June 21 to September 5, 2018, we conducted semi-structured interviews with private forest landowners (NIPFs, TIMOs, REITs, and other large corporate landowners) who manage pine plantations and natural pine forests in Alabama, Florida, and Georgia. From February 4 to April 5, 2019, we conducted additional semi-structured interviews with regional and state foresters, logging contractors, and biomass production facility managers. We selected our first tier of research participants from state forestry association lists, university extension program lists, and company websites,

and by contacting forestry professionals. We used snowball (referral) sampling to recruit additional research participants. Our study was approved by the University of Florida Institutional Review Board (IRB201800904).

2.3 | Interview questions

Semi-structured interviews use initial predetermined questions to collect detailed qualitative information from research participants, while allowing respondents to introduce new topics relevant to the prepared interview questions (Berg et al., 2004). We asked research participants to describe their experiences and perspectives regarding wood-based biomass production for bioenergy in the Southeast. Semi-structured interviews with private forest landowners covered the following six topics: (a) details of landowners' properties and income-generating activities; (b) motivations and preferences for forestland management; (c) current and projected forest management plans; (d) knowledge and opinions of wood-based biomass production; (e) barriers to and concerns about participating in wood-based biomass production; and (f) preferences for policies and programs to promote wood-based biomass production. We pretested these questions with five expert reviewers (professors and forestry extension professionals) before conducting interviews with landowners. Semi-structured interviews with additional key stakeholders covered the following four topics: (a) landowner knowledge of biomass production opportunities; (b) benefits and drawbacks to expanding wood-based biomass production; (c) barriers to participating in wood-based biomass production; and (d) policy preferences for promoting wood-based biomass production. We pretested these questions with three expert reviewers (professors and forestry extension professionals) before conducting interviews with these additional stakeholders. We ceased interviews both because of a high degree of overlap in our findings (i.e., data saturation), and because we were no longer able to recruit additional participants.

2.4 | Data analysis

We transcribed the interviews and then content analyzed the transcripts using ATLAS.ti, a software developed to conduct qualitative analysis of textual, graphical, audio and video data. We produced codes representing common units of information across interviews (Hsieh & Shannon, 2005; Kondracki et al., 2002). We then organized these codes into categories and broader themes (Ryan & Bernard, 2003). Both authors analyzed the interview transcripts independently, and then compared their analysis to ensure consistency of results.

3 | RESULTS

We completed interviews with 10 NIPF landowners in Florida, 10 NIPF landowners in Georgia, and five NIPF landowners in Alabama, with properties ranging in size from 38 to 3700 acres, distributed across 22 counties. We completed eight interviews with REITs, TIMOs, and other large corporate forest landowners, all with >40,000 acres of forestland under management. For all REITs, TIMOs, and other large corporate forest landowners, we interviewed managers whose responsibilities encompassed managing timberlands and forestry operations in the study region because these individuals were well positioned to provide insights on their company's investment in wood-based biomass production and potential barriers to biomass production. The average interview time for private forest landowners was 34 min. We conducted interviews with two forestry professionals, two biomass production facility managers, and two logging crew managers. The average interview time for these additional stakeholders was 39 min. We derived four themes from content analysis of the interview transcripts:

- Biomass production may support multiple land management objectives;
- Biomass production may allow for diversified income from timber production;
- Financial barriers to biomass harvesting exist along the supply chain; and
- Government subsidies are necessary but not sufficient to attain sustained biomass production in the Southeast.

3.1 | Theme 1: Biomass production may support multiple land management objectives

In general, landowners managed their land for multiple benefits (e.g., timber production, hunting, biodiversity conservation), with corporate landowners, REITs, and TIMOs placing greater emphasis on timber production to maximize financial returns for their clients. Landowners who had previously participated in biomass production stated that biomass production may be used to improve timber production ($n = 13$), enhance fire management ($n = 5$), and restore longleaf pine habitat (which also benefits wildlife and biodiversity and improves ecosystem function; $n = 5$). Respondents noted that biomass harvesting clears sites for replanting with timber stands and increases the amount of land that can be allocated to pines by removing undesirable plant species (including hardwoods) and harvest debris piles. A NIPF landowner explained, "biomass production is a very good tool to use in managing forestlands. You reduce the amount of residual debris left on the site after harvesting... It increases your

options for managing a young stand. You can cull ... small trees, undesirable trees, invasive plants... You can ... open up stands that are too thick.”

Respondents noted that removing harvest debris to supply biomass reduces potential uncontrolled fire and smoke hazards, which is particularly important because southeastern forests are becoming increasingly fragmented and developed and the ability to apply prescribed fire is declining. Respondents also suggested that by reducing the fuel load on private lands, biomass harvesting may help to facilitate the reintroduction of fire to the landscape in areas where prescribed burning is possible. Finally, respondents considered how their forest management affected habitat and wildlife. Some landowners used biomass harvesting to clear land for longleaf pine habitat restoration by removing hardwoods from areas that were historically pine- and fire-dominated. NIPF landowners stated that good forest management supports wood production, wildlife conservation and recreation, for example: “I’m of the opinion if you properly manage your forest for revenue then you also properly manage your wildlife, including non-game.” By contrast, an industrial forest landowner stated, “our primary driving factor is obviously making money... but if we can manage for wildlife we always try to do that.”

Landowners' focus on multiple land management objectives and outcomes was epitomized in their opposition to exotic wood-based feedstocks and dedicated short-rotation biomass production. Respondents ($n = 9$) expressed concerns that these biomass production practices would preclude timber production for higher valued product classes, increase erosion and reduce water quality owing to increased clear-cut frequency, increase herbicide use, reduce hunting quality, introduce invasive species by encouraging landowners to plant exotic wood-based feedstocks (e.g., eucalyptus), reduce biodiversity, and/or undermine the aesthetic value of forests. For example, one NIPF landowner stated “So, if folks to meet biomass demand go and take a forest that is loblolly, slash, and longleaf with the normal mix of hardwoods and ground forbs and grasses and all of that comes in a southern forest—all of which is valuable to the animals, and the insects, and the birds, and everything—and you replace it with eucalyptus to feed a biomass plant, I’m going to be pretty hard pressed to tell you that’s a good thing.” Despite these concerns, landowners noted that pilot tests of exotic wood-based feedstocks had not proven profitable owing to winter dieback and higher herbicide requirements.

3.2 | Theme 2: Biomass production may allow for diversified income from timber production

Nearly every landowner ($n = 32$) was willing to consider harvesting biomass as a byproduct of traditional wood production

to complement the production of other higher value products (e.g., sawlogs, chip-n-saw, pulpwood). Respondents stated that an abundance of non-merchantable wood remains on site after traditional wood products are harvested. This non-merchantable wood currently is not cost-effective to harvest but could be supplied for biomass, for example:

- “There is a lot of logging slash leftover from every logging operation... There [are] limbs, and needles, and tops... runover pre-merchantable or non-merchantable hardwood... There’s millions of tons a year in the state of Georgia that ... are available if there were an economical way to harvest them and transport them” – Large corporate landowner.
- “We have an oversupply of that small wood... So, it’d be helpful to have a competitor... In fact, it’s difficult in some cases to get the young stands thinned right now because the market is just not there” – NIPF landowner.

Both landowners and stakeholders in the biomass supply chain ($n = 27$) stated that, at current prices, landowners' primary financial motivation for engaging in wood-based biomass production is to reduce or offset site preparation costs associated with timber production. While seldom profitable for the landowner, biomass harvesting reduces the costs associated with clearing land and applying herbicides, for example:

- “Typically, a landowner gets \$0.50 to \$2 a ton stumpage for biomass so it’s not something that we make economic decisions around but it’s an important land management tool” – Industrial landowner.
- “We can spend a lot of money in mechanical site prep having to treat slash whether we rake it, shear the site, and acreage lost in windrows or slash piles... so very substantial cost if you spread it out across the land base. But ultimately if we could develop a strong biomass market, I would love it if ... the cash flow exceeded the savings that we got from site prep. That would be fantastic and certainly during the BCAP program that’s where we were. We made very substantial revenue... for biomass products” – Industrial landowner.

Both NIPF and industrial landowners ($n = 28$) stated that if biomass prices received by landowners increased they would harvest biomass to diversify their incomes, increase their profits or secure the financial viability of their forestlands. NIPF landowners tended to focus on biomass as a potential means to maintain land as a family asset, secure land for future generations, pay taxes on land, provide funds for college tuition or retirement, buy new machinery for land management, and/or offset lower timber prices. Exemplar quotes included:

- “You can't afford to buy land now and plant trees and think you're going to make any money. Of course, I inherited the land but ... I used to sell pine saw logs for close to \$60 a ton and now it's \$22 a ton. That's why people are not replacing the trees as much” – NIPF landowner.
- “You've got management costs. You've got property taxes. You've got liability insurance. There are costs to managing and owning land. If you can't cover those costs you've got to sell it, and that's a sad thing when you've had a piece of property in your family for a hundred years” – Industrial landowner.
- “We have not nearly enough markets if you look at the number of acres of pineland that we have planted in our three or four county area here [in central Alabama]... So, we need other options. It's of grave concern to put in the money for a 30-year investment. And to be uncertain about your markets is not real comforting” – NIPF landowner.

3.3 | Theme 3: Financial barriers to biomass harvesting exist along the supply chain

Respondents argued that low production of biomass in the Southeast is predominantly attributable to volatility in the wood-based biomass market. One representative from a TIMO, who has worked in the forest products industry for 18 years stated, “biomass markets fluctuate much more dramatically than other wood products markets.” In part, respondents attributed market volatility to price competition from higher-value wood products and other energy sources, for example natural gas. A large corporate landowner stated, “I don't think the biomass industry could compete economically with chip-n-saw and saw timber and poles and pulpwood... [For biomass to succeed it must] capture that understory, ... the limbs and the tops from the woods, and ... the unmerchantable hardwoods.” A NIPF landowner stated, “natural gas is killing the biomass market now. It's a young market that is going through growing pains.” Respondents ($n = 5$) also stated that negative public perceptions related to biomass are hindering the growth of the domestic market, for example: “Biomass for electricity has really received a lot of negative press and there's a lot of debate around carbon neutrality ... My concern is that markets will not be stable until the public perception of using wood for heat or power from well-managed forests changes.” Although there is international demand for biomass, respondents ($n = 4$) were concerned about the long-term sustainability of international markets, especially if European governments disallow wood-based bioenergy in their renewable energy mandates. As one corporate landowner stated, “from the pellet industry as I understand it 100% is going overseas. So, if that mandate quits, I would say it's not a viable option.”

Respondents ($n = 6$) also stated that the volatility of the biomass market has been exacerbated by erratic and limited domestic political support for biomass production. Respondents opined that policy changes, short-term government subsidies, and uncertainty regarding the regulatory environment have undermined market participants' trust in the wood-based biomass market and hence their willingness to invest in biomass facilities and equipment. Three respondents noted that the BCAP program, which was intended to be a 10-year program, was only implemented for 18 months. They also argued that BCAP did not disburse funds effectively, for example: “mills got all the BCAP money for doing something they were doing anyway [burning waste wood to power their facility].” An industrial landowner stated, “BCAP failed [because] a lot of the contractors said, ‘Okay, well that's just because the federal government is throwing a lot of money at this right now. I don't want to invest \$500,000 or a million dollars to get a chipper and all these chip vans because this could go away as fast as it came on’. And sure enough, that was the case. BCAP didn't last very long. So, you need to establish that trust, especially with the logging contractors because those are the folks that have to actually invest in semis and chip vans and chippers or grinders. I think [wood-based biomass is] an easier sell to the landowner. And that's always been the challenge.”

Other respondents ($n = 8$) reinforced the point that market volatility has undermined loggers' willingness to invest in expensive, specialized machinery that is needed to harvest biomass. Respondents also stated that market volatility has delayed or undermined investment in biomass facilities, which increases the costs of hauling low-grade wood long distances to the few biomass facilities in the Southeast ($n = 19$). Exemplar quotes included:

- “I'm not willing to produce [biomass] along with my logging because it is so undependable. To go to that extra expense of buying a chipper, buying chip vans, having to have that extra trucking capacity, I'm better off just to do the logging that I know I can make money at that's a dependable source of income” – Logging operations manager.
- “Biomass production from a cost standpoint in today's current market is a very, very thin margin of business... the delivered cost of the product is just enough to cover the freight and maybe 5% more of the overall cost of production of that material” – Logging operations manager.

Respondents ($n = 7$) noted, however, that biomass production could provide an additional income stream for sawmills. Sawmills could sell chips and shavings from sawtimber processing for wood pellet production. As a representative from a TIMO stated, “It would help those sawmills with their economics, and that provides us with a stable healthy market to sell sawtimber products into.”

3.4 | Theme 4: Government subsidies are necessary but not sufficient to attain sustained biomass production in the Southeast

Respondents were not uniform in their opinions about how wood-based biomass production in the Southeast could be increased. A subset of respondents ($n = 3$) advocated for long-term government subsidies to secure capital investment in biomass equipment and facilities. For example, one industrial forest landowner stated, "I would want to see some sort of long-term commitment from the government because they need to appreciate the fact that contractors need to put down a substantial capital investment to get equipped for biomass harvests. It just simply isn't fair to subsidize something for a short window of time and then leave contractors and/or landowners hanging at the end." Other respondents ($n = 3$) also advocated for initial government subsidies to seed the biomass industry but argued that long-term biomass production could only be secured if the biomass market is price competitive and profitable. For example, a NIPF landowner said, "I think we are going to have to rely on the free market to [secure biomass production]. It might have to have some sort of financial supplement to get it started and get the interest in it."

In addition to suggestions on how the biomass supply chain could be secured, respondents stated that improved outreach to forest landowners is required to inform them about biomass production. Both NIPF and industrial landowners ($n = 26$) were interested in educational programs regarding multiple-use management for wood-based biomass production, including how biomass production could complement their land management objectives (e.g., habitat restoration, hunting, improved timber production). NIPF landowners expressed confusion about what raw materials are suitable for sale into the wood pellet and biomass chip markets, how to participate in biomass markets, and which facilities purchase wood for biomass.

Many NIPF landowners ($n = 11$) were either uncertain about the forest certifications on their land or lacked the appropriate certifications needed to supply wood-based biomass to the UK and EU markets. However, multiple landowners mentioned that they were enrolled in other stewardship programs that require them to engage in multiple use forest management that is in accordance with best management practices (e.g., the Alabama Forest Stewardship Program, the Alabama TREASURE Forest certification, the Florida Forest Stewardship Program, the Georgia Forest Stewardship Program) or that they were members of stewardship groups (e.g., the Longleaf Alliance). As noted by an NIPF landowner, landowner enrollment in the certifications needed to supply the wood-based biomass markets is "held back by [lack of] awareness and education." Biomass production facilities stressed the importance of these certifications,

in particular that they cannot source wood-based biomass from forestlands that will be converted to other uses after harvest. For example, "We will not accept wood from any type of land use change. So, if the land is being converted to agriculture, to pasture, to parking lots ... if it's not going back into forest, we will not accept that material. And that is driven by the sustainability requirements of the countries that we sell our pellets to overseas. And that is the one line that we cannot cross."

3.5 | Limitations

Our results provide insights into the wood-based biomass market in the Southeast, but there are limitations to this study. First, because this research is qualitative, our findings cannot be generalized to all stakeholders in biomass production in the Southeast. Although we followed the appropriate steps to ensure reliability of our data analysis, we did not member check our findings with any research participants. Second, our study was designed to elicit key stakeholders' opinions on how wood-based biomass production in the Southeast could expand further. Our study was not designed to investigate social or environmental justice concerns related to wood-based biomass production in the Southeast.

4 | DISCUSSION

If demand for wood-based biomass continues to expand, the Southeast has the necessary capacity in terms of available wood fiber to meet this demand, in addition to the market advantage of relatively low shipping costs to the UK and EU (Henderson et al., 2017). Feasibility analysis of wood pellet plant development suggests that Alabama, Florida, and Georgia could sustain an additional 32, 16, and 26 wood pellet mills, respectively, based on current pulpwood uses in these states (Henderson et al., 2017). The private landowners we interviewed stressed their interest in supplying wood-based biomass as a byproduct of harvesting other higher value products (e.g., sawlogs, chip-n-saw, pulpwood), especially if the prices received by landowners for wood-based biomass increase. Landowners wanted to find markets for the non-merchantable wood that remains on site after traditional wood products are harvested or timber stands have been thinned. Primary residuals and non-sawtimber roundwood are well suited to wood pellet production, and foresters and loggers play a key intermediary role in facilitating the supply of these wood fibers to pellet plants (Kittler et al., 2020). However, research participants argued that market volatility and inconsistent government support (e.g., the abortive BCAP program) has undermined loggers' willingness to invest in expensive, specialized machinery that is needed

to harvest biomass. They also argued that market volatility, intermittent government support and uncertainty about how sustainability concerns will affect future international demand for wood-based biomass have reduced potential investment in wood pellet plants, thereby increasing the costs of hauling low-grade wood long distances to existing, operational facilities in the Southeast. Landowners who had participated in biomass production agreed that opportunities to sell biomass have been sporadic because wood pellet plants have not operated continuously and dependably (Mayfield et al., 2007). According to research participants, uncertainty about the future financial viability of wood-based biomass production has reduced wood suppliers' (loggers, foresters) interest in wood-based biomass harvesting on private lands and landowners' ability to access these markets. The costs of harvesting and transporting biomass to pellet mills, price competition from other wood products, and low biomass stumpage prices have reduced the potential rate of wood-based biomass harvest on private timberlands in the Southeast (Dwivedi & Alavalapati, 2009).

Our research participants also argued that price competition from fossil fuels and other renewable energy sources in the United States has limited production of wood pellets to supply the domestic market, which means that available wood-based biomass in the Southeast is not being used to attain renewable fuel production in the United States. Electricity is primarily generated from natural gas (38.4% of domestic energy generation) and coal (23.5% of domestic energy generation) in the United States. In 2021, coal and natural gas were priced at \$2.35/million British thermal units (mmbtu) and \$2.73/mmbtu, respectively, whereas densified wood for energy production was priced at \$10.94/mmbtu (U.S. Energy Information Administration, 2021a, 2021b, 2021c). Because wood-based biomass is still not price competitive with alternative energy sources wood pellet production in the Southeast is likely to remain reliant on international demand, which means that sustainability standards must be met to secure future biomass production in the Southeast (Hodges et al., 2019a).

As noted by our research participants, concerns about the sustainability and carbon neutrality of wood-based biomass production have been raised both domestically and internationally, resulting in the call to meet sustainability standards along the wood-based biomass supply chain (Dale et al., 2016; Hodges et al., 2019a; Kittler et al., 2020). These standards have been implemented in response to concerns that increased demand for wood fibers to supply wood-based biomass may cause major forestland losses or degrade forests' structure, composition, and nutrient cycles (Aguilar et al., 2020). Although proponents argue that wood-based biomass markets may prevent deforestation and increase investment in multi-purpose tree plantations (Aguilar et al., 2020), sustainability standards have been created to ensure

carbon neutrality, reforestation after wood harvest, protection of biodiversity, and compliance with best management practices to maintain environmental quality (e.g., water or soil quality) when producing wood-based biomass (Dale et al., 2016). Importantly, wood fibers cannot be harvested from forestland that is legally withdrawn from timber production (Aguilar et al., 2020). The SBP, which is a private certification system that is designed to ensure legal and sustainable sourcing of wood pellets, relies on existing sustainable forest management and chain-of-custody certificate programs (e.g., the FSC; Aguilar et al., 2020). It is therefore concerning that multiple landowners, notably NIPF landowners, were uncertain whether they held the appropriate certifications to supply wood-based biomass to the international markets or did not recognize the names of these various certifications.

Nonetheless, our research participants, particularly the NIPF landowners, stressed the importance that they place on land and forest stewardship, which is commensurate with sustainability standards. Consistent with findings by Hodges et al. (2019a), landowners managed their land for multiple benefits and argued that wood-based biomass production may be used to improve timber production, enhance fire management, restore longleaf pine habitat, and support wildlife by enhancing habitat quality. Their opposition to exotic feedstocks (e.g., eucalyptus) and short-rotation woody crops was based on concerns about increased erosion, reduced water quality, increased herbicide use, reduced biodiversity, the introduction of non-native species, and reduced aesthetic and cultural values of forests. As such, our research participants appeared to apply the same principles to managing their land that are encompassed in sustainability standards. However, NIPF landowners' concerns about the future profitability of timber production suggest that some landowners may not reforest their land after harvest, which is not consistent with sustainability criteria for wood-based biomass production. Higher prices for wood-based biomass harvesting could help NIPF landowners to maintain their lands as forest by allowing them to generate sufficient revenues to offset land management costs and other expenses. By contrast, institutional and industrial landowners, notably TIMOs, are highly likely to reforest timberland after harvest (Sun et al., 2015), which is critical to meeting international biomass sustainability requirements. Analysis by Aguilar et al. (2020) also suggest that although wood pellet production has increased carbon pools in live trees, the wood-based biomass procurement areas of large-scale wood pellet mills in the Southeast have lower carbon stocks in soils and fewer standing-dead trees, which is not consistent with sustainability standards.

While there is an abundance of wood that landowners are willing to supply for biomass production, notably non-merchantable woody material and debris associated with wood production for traditional forest products (e.g., pulpwood, sawtimber), landowners' access to biomass markets will depend on meeting sustainability standards. As noted by

Kittler et al. (2020), meeting these sustainability standards is hampered by wood dealers' and suppliers' lack of understanding of the importance of using risk-based systems to source biomass and the fact that smaller landowners typically do not have appropriate sustainability certifications (see also Hodges et al., 2019a). Although many NIPF landowners implement best management practices pertaining to timber harvesting, reforestation and environmental quality, a survey by Hodges et al. (2019a) found that 20% of NIPF landowners in the Southeast did not know if best management practices are implemented on their land, possibly because they hire professional foresters to manage their land. Stakeholders in wood-based biomass production (feedstock production, supply, and procurement) require training in sustainable landscape design and assistance in obtaining appropriate sustainability certifications to facilitate improved utilization of available wood-based biomass for bioenergy production (Dale et al., 2016; Hodges et al., 2019a; Kittler et al., 2020). NIPF landowners may also benefit from reforestation cost-share programs to ensure that they reforest their land after harvest (Sun et al., 2015).

However, landowners may not invest in the process of sustainability certification unless they receive higher prices for wood-based biomass production. Both NIPF and industrial landowners argued that the prices they receive for wood-based biomass are low, which reduces the profitability from supplying wood-based biomass to pellet mills. While landowners were interested in adopting biomass production on their land to complement their land management objectives, currently their financial incentive to harvest biomass is small. Our findings are consistent with Hodges et al. (2019b) who found that NIPF landowners are more likely to engage in wood-based biomass production if they are assured of a long-term market, biomass prices increase, and they receive technical assistance that allows them to harvest woody biomass in a manner that improves stand productivity and future value. Several landowners lacked knowledge on how to pair biomass harvesting with traditional wood production or how to access biomass markets (Joshi & Mehmood, 2011a, 2011b; Joshi et al., 2013). They would benefit from outreach programs about wood-based biomass production, especially if paired with sustainability certification.

Although landowners were interested in biomass production to the extent that it complemented their land management objectives, loggers' and foresters' uncertainty about the future trajectory of both domestic and international biomass markets appear to have played a key role in keeping actual biomass harvests below potential harvests. This uncertainty translated into unwillingness to invest in costly equipment to harvest wood-based biomass and transport it to markets, even when government subsidies were offered. Government subsidies that are designed to ensure investment in biomass harvesting equipment by loggers and the establishment of additional biomass facilities (thereby reducing the costs of

hauling biomass) may help to attain full biomass harvest potential in the Southeast. However, unless loggers, production facilities and other key stakeholders in biomass production trust that biomass for bioenergy will expand and persist, they will have little incentive to develop cost-effective technologies or invest in the biomass supply chain.

5 | CONCLUSION

Despite increasing international demand for wood-based biomass for bioenergy, biomass production in the Southeast remains low compared to other wood products such as pulpwood and sawtimber. There is sufficient wood-based biomass in the Southeast to support far greater production of wood pellets for domestic and international markets. While landowners who participated in our study were willing to supply woody debris and non-merchantable wood for bioenergy production, even at current low stumpage prices, they preferred to receive higher prices for wood-based biomass to offset their land management costs and expenses. Loggers' reluctance to invest in the expensive specialized equipment needed to harvest biomass and the fact that there have been few continuously operating biomass production facilities in the Southeast (which increases the transportation costs associated with biomass production) have meant that actual biomass harvests are below potential harvests. Loggers' and investors' incentives to invest in wood-based biomass production have been undermined by inconsistent domestic government support for biomass production and concerns about the loss of the import market as a result of international concerns about the sustainability of wood-based biomass. These concerns could be addressed if stakeholders in wood-based biomass production (feedstock production, supply, and procurement) obtained appropriate training in sustainable landscape design and assistance in obtaining sustainability certifications to offset international concerns about the sustainability of wood-based biomass production.

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CONFLICT OF INTEREST

None.

DATA AVAILABILITY STATEMENT

Research data are not shared, owing to ethical restrictions related to human subjects research.

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