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Efficacy of carbon and bioenergy markets in mitigating carbon emissions on reforested lands: A case study from Southern United States

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ABSTRACT

Carbon markets would encourage forest landowners to increase rotation ages of their plantations. Emerging wood-based energy markets would increase prices of small-diameter timber products, thereby encouraging forest landowners to possibly opt for shorter rotation ages. We developed a comprehensive forest carbon model to track four carbon pools (carbon related to silvicultural activities, carbon sequestered on forestlands, carbon sequestered in wood products and wood present in landfills, and avoided carbon emissions) at the stand level to determine efficacy of carbon and bioenergy markets in mitigating carbon emissions with and without any change in rotation ages. Slash pine (*Pinus elliottii*) – a common species planted across the Coastal Plain of Georgia and Florida was taken as a representative species. We find that an increase in rotation age does not necessarily transform into additional carbon savings relative to some base rotation ages over a planning horizon of 100 years. Similarly, a decrease in the rotation age is not necessarily beneficial from carbon perspective either with respect to some base rotation ages. The utilization of all timber products for manufacturing of wood pellets to generate electricity in the United Kingdom maximizes carbon savings without any change in the rotation age. Suitable safeguards need to be incorporated in existing forest and bioenergy certification schemes to ensure efficacy of reforested lands in mitigating carbon emissions. Climate policies should emphasize on a systemic approach to maintain carbon mitigation potential of the forestry sector over time.

1. Introduction

About 28 million metric tons of forest carbon credits (carbon dioxide equivalent) worth US $ 216 million were traded in 2012 globally out of which about 30% were traded in North American only (Forest Trends, 2013). It is quite likely that forest carbon markets will expand further as several multinational corporations, governmental agencies, and non-governmental organizations are interested in buying forest carbon credits to offset their greenhouse gas (GHG) emissions. Existing studies suggest that forest carbon markets would encourage forest landowners to increase rotation age of their plantations as additional carbon sequestered on their forestlands will provide monetary benefits to them (Dwivedi et al., 2012b; Gutrich and Howarth, 2007; Sohngen and Brown, 2008; van Kooten et al., 1995).

At the same time, manufacturing of wood pellets is rapidly expanding in the United States mostly to meet demand from European countries where wood pellets are increasingly being used as a feedstock for electricity generation. In fact, the United States has become the largest exporter of wood pellets in the world primarily to the European Union (Ekstrom, 2012). It is projected that the exports of wood pellets would reach to about 6.0 million metric tons by 2016 (Lang, 2014) totaling US $1000 million at current market rates. Existing studies suggest that the demand for wood pellets will increase prices of small-diameter wood products in domestic markets (Abt et al., 2012, 2010; Guo et al., 2011). This increase in prices could encourage forest landowners to decrease the rotation age of their plantations as availability of small-diameter wood products, especially pulpwood is high for early plantation ages (Yin et al., 1998).

No study, to the best of our knowledge, has analyzed the consequence of a change in the rotation age on total carbon savings over time by considering all the major forest carbon pools (carbon related to silvicultural activities, carbon sequestered on forestlands, carbon sequestered in wood products and wood present in landfills, and avoided carbon emissions) together at the stand level using common system boundaries and under similar set of assumptions for reforested lands.

The majority of existing studies focusing on the role of emerging carbon markets on the forestry sector have focused on the impact of carbon prices on the profitability of forest landowners at the stand level (Dwivedi et al., 2009; Stainback and Alavalapati, 2002), quantifying changes in timber markets (Alig and Butler, 2004; Sohngen and

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Sedjo, 2000), and projecting land use changes (Lubowski et al., 2006). Similarly, the majority of studies focusing on emerging markets for wood-based energy products have focused on the carbon intensity of wood-based energy products (Damen and Faaij, 2006; Dwivedi et al., 2012a, 2011), stand-level economics (Susaeta et al., 2009), market equilibrium (Abt et al., 2012; Daigneault et al., 2012), and direct-indirect land use changes (Daigneault et al., 2012; Searchinger et al., 2008; Wang et al., 2015). This missing information is critical from a climate policy perspective to strengthen the role of forestry as an effective tool for carbon mitigation (Woodbury et al., 2007) especially when forestry is considered as a low cost carbon mitigation option (McCarl and Schneider, 2001; Richards and Stokes, 2004).

2. Methods

This study analyzed four different scenarios (Table 1). A total of 82 different cases ((two forest management choices (intensive and non-intensive) and 41 rotation ages (10 to 50 years in annual steps)) were analyzed under each scenario when the original rotation age did not change over a 100 year planning horizon. However, a total of 3280 different cases ((two forest management choices (intensive and non-intensive), 41 original rotation ages (10 to 50 years in annual steps), and 40 new rotation ages (10 to 50 years in annual steps excluding the original rotation age)) were analyzed under each scenario when the original rotation age did change at the onset of planning horizon of 100 years. We tracked trajectory of all selected carbon pools for all the cases present under each scenario (Figure S1).

Under intensive forest management, herbicides (at plantation establishment year) and fertilizers (at 2nd and 12th year of plantation) were applied (Yin et al., 1998). These inputs were not used under non-intensive forest management (Yin et al., 1998). For each scenario, four carbon pools were considered: carbon sequestered in above- (live timber products, dead trees, foliage, forest floor, and understory vegetation) and below-ground biomass (coarse roots); carbon emissions from silvicultural practices; carbon sequestered in wood products and wood present in landfills; and avoided carbon emissions due to the substitution of grid electricity with the electricity generated using wood pellets in the United Kingdom.[1] This study focuses on the southern United States as this region supplied about 62% of total roundwood in 2006 at the national level (Smith et al., 2009). This region is also a major exporter of wood pellets to the European countries supplying about 98% of all exported wood pellets (Ekstrom, 2012). Slash pine (*Pinus elliottii*) was selected as a representative species due to its popularity among forest landowners in the Coastal Plain of Georgia and Florida (Smith et al., 2009).

A growth and yield model of slash pine was used to estimate availability of three timber products (sawtimber, chip-n-saw, and pulpwood) from a hectare of slash pine plantation for intensive and non-intensive forest management choices (Yin et al., 1998). Intensive and non-intensive forest management choices were selected to reflect active and passive forest landowners, respectively. The availability of logging residues at any harvest age was calculated as the difference between total biomass present in stems and total biomass present in merchantable portion of stems (sawtimber, chip-n-saw, and pulpwood) at the stand level plus 12% of all biomass present in merchantable portion of stems at a given rotation age (Alabama Forestry Commission, 2015). Additional 12% biomass was added as a proxy for biomass available in branches and tree tops. Total carbon sequestered in other above- and belowground pools was equal to the product of total carbon sequestered in timber products and an allocation ratio. The allocation ratio was 35% at the 10th year of plantation, 27% for plantation ages 11 to 20 years, 26% for plantation ages 21 to 30 years, and 25% for plantation ages 31 years and above (Gholz and Fisher, 1982; Gonzalez-Benecke et al., 2010). At any rotation age, quantity of carbon sequestered in timber products was added to carbon sequestered in other above- and below-ground pools to ascertain total carbon sequestered on a hectare of slash pine plantation. GHG emissions related to silvicultural activities were allocated to available timber products by the percentage weight contributed by each timber product towards their combined weight at any plantation age (Table S1).

[1] About 73% of total exported wood pellets from the United States are consumed in the United Kingdom (USEIA, 2015).

Table 1
Scenarios analyzed in the study. Scenario LEFT-LR assumes that a forest landowner is leaving logging residues in the field and all other timber products are being used for traditional purposes. Scenarios ENE-LR and ENE-LR + PW are considered as emerging pellet market is using pulpwood as a feedstock. Scenario ENE-ALL represents whole-tree harvesting for pellet production as envisioned by several non-government organizations for existing state of wood pellet production in the southern United States. A schematic of Scenario ENE-LR is present in Figure S1.

Scenarios	Sawtimber	Chip-n-saw	Pulpwood	Logging residues
LEFT-LR	Lumber	Lumber	Paper	Left on the ground
ENE-LR	Lumber	Lumber	Paper	Wood pellets[a]
ENE-LR + PW	Lumber	Lumber	Wood pellets	Wood pellets[a]
ENE-ALL	Wood pellets	Wood pellets	Wood pellets	Wood pellets[a]

[a] Only 30% of available logging residues are used for wood pellets and remaining 70% are left on the ground only.

This study assumes that a forest landowner will either maintain the original rotation age over the planning horizon or opt for a new rotation age (higher or lower) at the end of original rotation age and the beginning of the planning horizon (Fig. 1). Under the situation when a forest landowner maintains the original rotation age, the quantities of carbon sequestered in wood products and wood present in landfills[2] and avoided carbon emissions at the end of the planning horizon were added together to determine total carbon savings (Equation 1). We have not considered total carbon sequestered in above- and below-ground carbon pool to calculate total carbon savings when there is no change in the rotation age as net sequestered carbon does not change in this carbon pool over time.

Equation 1

Total Carbon Savings at the 100th year of Planning Horizon = Total Carbon Sequestered in Wood Products and Wood Present in Landfills at the 100th year of Planning Horizon + Total Avoided Carbon Savings at the 100th year of Planning Horizon.

In the situation where a forest landowner opts for a new rotation age, quantities of carbon sequestered in wood products and wood present in landfills and avoided carbon emissions were added together for the original rotation age and then subtracted from the sum of the quantities of carbon sequestered in wood products and wood present in landfills and avoided carbon emissions for the new rotation age to determine partial net total carbon savings at the end of planning horizon (Equation 2). Net change in carbon sequestered in above- and below-ground carbon pool between the original rotation age and a new rotation age was added to partial net total carbon savings to determine net total carbon savings (Equation 3). We have considered only net change in carbon sequestered in above- and belowground biomass over the planning horizon between any two rotation ages to determine total carbon savings as the same forestland is being used for growing slash pine over time.

Equation 2

Partial Net Total Carbon Savings at the 100th year of Planning Horizon = [Total Carbon Sequestered in Wood Products and Wood

[2] The carbon sequestered in leftover logging residues was also added to this carbon pool for all scenarios.